# SPECIFIC GRAVITY DETERMINATION OF MARINE SEDIMENTS

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# THESIS

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## ABSTRACT

Accurate specific gravity measurements are required for the analysis of physical properties of marine sediments. Application of the bottle pycnometer technique, the standard determination method, is time-consuming, tedious, and perhaps subject to inaccuracies in the case of fine particulate matter. A review of methods currently in use was conducted to ascertain the present state of the art and reveal any new developments in this field. Specific gravity values for three operating modes of the air comparison pycnometer, two of which use helium, were compared with bottle pycnometer values for four test materials. The air comparison pycnometer determinations, regardless of operating mode, resulted in higher specific gravities than their counterpart bottle pycnometer values for kaolinite, montmorillonite, and marine sediment samples. The use of helium as the comparison medium in the air comparison pycnometer appears to reduce the surface active characteristics of the colloidal material. Specific gravity determinations by all four test methods agreed very well for powdered quartz samples with a known specific gravity.

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# I. INTRODUCTION

Specific gravity by strict definition is the ratio of the mass of a given volume of a substance, at a stated temperature, to the mass of an equal volume of a reference substance, at a stated temperature [Thewlis, 1962]. It is common practice in soil engineering to use weight in place of mass in this definition, where weight is a force equal to the product of mass and the acceleration of gravity. In the case of marine sediments the specific gravity is usually referred to an equal volume of distilled water at $4^{o}C$.

The above definition allows the expression of three different forms of specific gravity. These are 1) the specific gravity of solids, $G_s$, 2) the apparent specific gravity, $G_a$, and 3) the bulk specific gravity, $G_m$. The specific gravity of solids is the ratio of the weight in air of a given volume of soil solids, exclusive of voids or impermeable pore spaces, at a stated temperature, to the weight in air of an equal volume of distilled water at $4^{o}C$. Apparent specific gravity is the ratio of the weight in air of a given volume of soil solids plus the voids and pore spaces normal to the material, at a stated temperature, to the weight in air of an equal volume of distilled water at $4^{o}C$. The bulk specific gravity is the ratio of the weight in air of a given volume of a permeable material (including material solids, impermeable voids or pores, and interstitial spaces between adjacent particles), at a stated temperature, to the weight in air of an equal volume of distilled water at $4^{o}C$.

The specific gravity of solids applies to fine particulate matter, and is a parameter frequently determined in the analysis of the physical properties of marine sediments. The other two forms of specific gravity are usually related to coarser material and are used in other aspects of soil mechanics practice [Office of Chief of Engineers, 1965]. The specific gravity of solids is synonymous with the terms absolute, true, or real specific gravity. Unless otherwise modified, the term specific gravity will here refer to the specific gravity of solids.

Specific gravity is a measure of, and a means of expressing, the relative heaviness of a material. The density of a marine sediment is defined as the weight per unit volume, and it is a measure of its denseness. Density is synonymous with the terms unit weight and specific weight, and is usually expressed in units of pounds per cubic foot or grams per cubic centimeter, whereas specific gravity is a unitless ratio. Dry density is directly proportional to specific gravity, if the relative volumes of solid particles and void spaces are maintained constant.

Specific Gravity as a Physical Property of Marine Sediments

The specific gravity can be used as a very precise index property for the identification of minerals. The specific gravity of a marine sediment represents the weighted average of the specific gravities of all the various mineralogic constituents of the sediment. The specific gravities of these constituents may vary widely. Gypsum has a specific gravity of about 2.3, whereas hematite has a specific gravity of 5.3. The great preponderance in sediments of quartz, with a specific gravity of 2.65, and the other silicate minerals, usually narrows the range of specific gravities of sediments to values between 2.5 to 2.9. Some marine sediments are rich in calcium carbonate and would exhibit higher specific gravity values.

The value of the specific gravity is applied to several other calculations in the analysis of the physical properties of marine sediments. Its accuracy is of great importance in calculations of parameters such as void ratio, porosity, saturated void ratio, and sub-sieve grain size distribution.

## Basic Specific Gravity Determination

For a relatively large solid body the specific gravity is simply the weight of the body divided by the weight of an equal volume of water. Its determination is a three step procedure. First, the object is weighed. Next, the weight of an equal volume of water is determined. And finally, the weight of the object is divided by the weight of the equal volume of water. Determining the weight of the solid body presents no significant problem. Accurate determination of the volume of a solid is considerably more difficult. Twenhofel and Tyler [1941] indicate four basic methods are available for determining the specific gravity of a solid.

The volumetric method is appropriate if the solid body has a simple geometrical shape. The dimensions of the object are carefully measured, its volume calculated, and then the weight of an equal volume of water obtained. The hydrostatic method incorporates the use of Archimedes principle to experimentally determine specific gravity. This principle states that the buoyant force on an immersed body is equal to the weight of the liquid displaced by the body. A direct volume measurement of the object is not made as the loss of weight of the object in water represents the desired weight of an equal volume of water.

A third procedure for determining specific gravity is the flotation method, in which the specific gravity of a solid object is compared directly with a liquid of known specific gravity. When the solid will neither sink or rise in a liquid the specific gravity of the solid is the same as that of the liquid. The fourth method is the direct displacement method. A flask is filled with distilled water of determined temperature to a given volume mark and the flask is weighed. The sample is then added to the flask and the new volume and weight is noted. The specific gravity equals the difference in weights divided by the difference in volumes.

## Purpose of this Investigation

The specific gravity determination is relatively easy for a larger solid body. Marine sediments are colloidal, however, and the application of the above methods requires considerations that complicate the determination significantly. The volumetric method involves the problem of determining the volume of fine particulate matter. A sample of marine sediment consists of very fine grained particles with voids and interstitial passages that make this determination extremely difficult. Both the hydrostatic weighting method and the displacement method require the assurance that all the air is removed from the sediment immersed in the distilled water to ensure that the water is displaced only by solid material. All of these methods require detailed attention to the preparation of the sample.

The bottle pycnometer technique, which is an application of the hydrostatic weighing procedure, is considered the standard method for the specific gravity determination of soils and sediments. Application of this method is tedious, time consuming, and is of questionable accuracy in some cases. The results for sands and silts are believed to be accurate. Bottle pycnometer values for fine particulate material, such as clays, may be erroneous, but are usually consistent with strict adherence to the procedures. Incomplete air removal from the suspended sediment is the primary source of error and results in low specific gravity values. It is desirable to find a new and less time consuming specific gravity determination method and evaluate its accuracy and application with regard to marine sediments.

## II. REVIEW OF METHODS CURRENTLY IN USE

A review was made to determine the specific gravity determination methods presently being used throughout the technical fields, and to discover if any new methods were under development. A total of 327 letters were sent to selected academic institutions, manufacturing and distribution firms, soil mechanics and marine research laboratories, and individuals known to be working in the field of interest. The inquiries to academic institutions, laboratories, and private individuals consisted of a covering letter indicating the purpose of the correspondence together with a check - off type of questionnaire. Information was requested concerning the method, type of equipment, and accuracy of the specific gravity technique as utilized by the recipient. Sample copies of the covering letter and questionnaire are included in Appendix A. The commercial firms were asked for information concerning specific gravity determination equipment applicable to fine particulate solids. A copy of the letter to these firms is also included in Appendix A. Replies were received from 62 percent of these inquiries.

### Academic Institutions

The various departments of chemistry contacted indicated that no research was being conducted in the area of specific gravity determination of fine particulate matter. Of the 73 departments of geology queried, only six indicated specific gravity determinations were routinely made. Methods used were Berman Density Balance, bottle pycnometer, and density gradient columns. The departments of civil engineering responded almost unanimously with the bottle pycnometer method as their choice of a specific gravity determination technique. When dealing with soils and clays twenty-three schools used this method while only one school used the air comparison pycnometer for the specific gravity determinations. Three-quarters of the 34 departments of oceanography contacted answered the questionnaire, but only five of these indicated they were making analyses of marine sediments. Two use cylinders of a known volume plus the weight of the sample to determine wet density, two use the bottle pycnometer method, and one uses the air comparison pycnometer. A summary of institutions who responded annotated by comments of interest is included in Appendix B.

Manufacturing and Distribution Firms

A total of 72 companies were contacted. Six companies manufacture balances which are specifically designed for or may be modified to determine specific gravity using the hydrostatic weighing technique. Most notable of these are the Berman Density Balance and the Kraus Jolly Balance. Four other firms manufacture or distribute density gradient column systems which may be used for specific gravity determination. One firm manufactures a precision pressure gauge which can be installed in a system to determine the volume of a unknown sample size, and as such basically serves as the null pressure indicator in an air comparison pycnometer system to be described later. A summary of review results from the commercial firms may be found in Appendix B.

Laboratories and Private Individuals

Of the individuals and facilities sent questionnaires, six were using the bottle pycnometer method and three the air comparison pycnometer. Other replies indicated application of flotation methods, hydrostatic weighing methods, or bulk density measurements using a cylinder of known volume. Appendix B contains more detailed information concerning replies from laboratories and private individuals.

## Discussion of Results

This review confirmed that the bottle pycnometer is the primary method now in use for making specific gravity determinations of fine particulate materials such as sediments. Although some replies indicated that extreme accuracy was not required for their particular effort, the accuracy stated by most of the users of the bottle pycnometer technique was $\pm$ 0.005 to $\pm$ 0.01. Those interested in precise and reproducible readings emphasized the care required to de-air the sample and to maintain an adequate temperature control. To achieve desired accuracy one group evacuated the sample for 24 to 48 hours while continuously agitating the sample on a vibrating table. In another case a laboratory makes duplicate specific gravity determinations on two samples of a material and accepts the results if the values agree within $\pm$ 0.01.

Unfortunately no new techniques for the specific gravity determination of fine particulate material were uncovered. It was noted, in general, that those using the gas pycnometer were unsure of the accuracy of their results and for the most part did not use helium as the comparison medium. A majority of the replies indicated an interest in the results of the Naval Postgraduate School effort.

## III. PROCEDURES FOR SPECIFIC GRAVITY DETERMINATION

Standard procedures for analysis of the physical properties of marine sediments have not yet been established. Most of the techniques in use are modifications of those used in soil mechanics. The present study has revealed that five methods are in use for specific gravity determination. These procedures are summarized here in some detail. The bottle pycnometer method and the air comparison pycnometer method, both of which are utilized for a comparative analysis in this paper, are presented in as much detail as could be obtained. The other methods are less strenuously treated with regard to operating procedure, however the advantages and disadvantages of all methods are discussed in connection with their applicability to marine sediments.

### Bottle Pycnometer Method

This method is considered the standard for determining the specific gravity of soils, clays, and sediments. The loss of weight of the sample when immersed in water is obtained, and as such represents a variation of the hydrostatic weighing technique. The following procedure was extracted primarily from Lambe [1959] and A.S.T.M. [1964].

1. Apparatus Required

a. Pycnometer - volumetric flask of 100 or 500 milliliter capacity, or stoppered bottle of at least 50 milliliter capacity.

b. Balance - sensitive to 0.01 grams if volumetric flask used, or 0.001 grams if stoppered bottle is used.

c. Distilled water

d. Vacuum source (optional)

e. Heat source - burner or hot plate

f. Drying oven - capable of maintaining $105^{\circ}C \pm 5^{\circ}C$ temperature.

g. Desiccator

h. Thermometer - graduated to $0.1^{\circ}C$.

i. Evaporating dishes.

j. Medicine dropper or pipette.

2. Calibration of Pycnometer

For every specific gravity determination the weight of the pycnometer filled to the calibration mark with distilled water at the test temperature is required. A calibration curve for each pycnometer may be plotted, which allows this value to be obtained graphically for any test temperature.

a. The thoroughly cleaned and dried pycnometer is weighed, and the weight is recorded ($W_f$). The cleaning procedure requires washing with glassware cleaner, rinsing with distilled water, rinsing with alcohol to remove water, and a final rinse with ether to remove the alcohol.

b. The pycnometer is filled with distilled water to the calibration mark, and the weight of the pycnometer and water is recorded ($W_a$). The temperature of the water is recorded to the nearest $0.1^{\circ}C$ ($T_i$). Extreme care must be exercised to ensure that the water is well mixed and that the recorded temperature represents the true temperature of the water. The height of the thermometer bulb within the water should be noted so that the bulb may be held at the same level for subsequent readings.

c. The weight of the pycnometer plus distilled water for any temperature ($T_x$) can be caluclated from the formula

$$W_a(T_x) = \frac{\text{density of water at } T_x}{\text{density of water at } T_i}\left[(W_a(T_i) - W_f) + W_f\right] \qquad (1)$$

d. Densities for various temperatures may be inserted in this formula to obtain values for the calibration curve. Figure 1 is an example of a calibration curve for a 100 milliliter pycnometer.

3. Sample Preparation

The sediment sample may be either at its natural water content or oven-dried, and slightly different procedures are prescribed for each case. Only the oven-dried sample procedure will be outlined here. The material is dried for at least 12 hours, or to constant weight, in an oven maintained at $105^\circ C \pm 5^\circ C$. The sediment particles contain a film of absorbed water which must be removed, and the specific gravity obtained is dependent to some extent on the method of drying employed [Lambe, 1949]. Careful control of the drying is required for all samples of the same material for consistent results. Upon completion of the drying period the samples are cooled to room temperature in a desiccator.

4. Specific Gravity Determination Procedure

a. An oven-dried sample of at least 25 grams is added to a 100 milliliter volumetric flask, and the sample dry weight, $W_o$, is recorded to the nearest 0.01 grams.

b. Distilled water is added to the flask, and the sample is allowed to soak for 12 hours.

c. Additional distilled water is added to fill the flask about three-fourths full.

d. The entrapped air is removed by i) gently boiling for ten minutes while continually agitating the sample, or ii) applying a

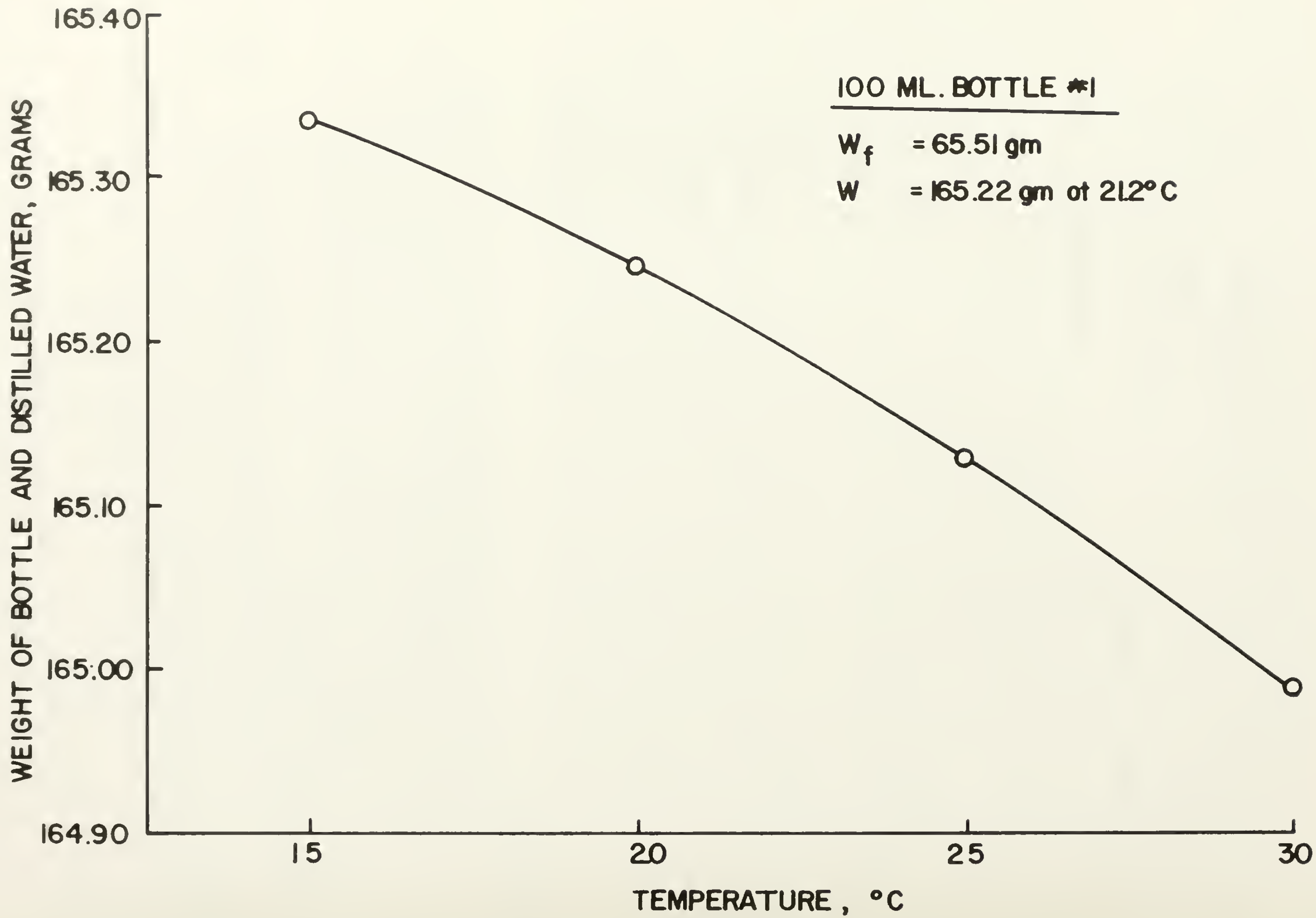


Figure 1. Calibration Curve for 100 Milliliter Pycnometer Bottle.

vacuum, not exceeding 100 millimeters of mercury, to the flask. For oven-dry samples approximately two to four hours of vacuum application are usually necessary.

e. If the sample is boiled to assist in removal of air, it is allowed to stand, preferably overnight, to cool to room temperature.

f. The flask is then filled with distilled water until the bottom of the meniscus is even with the calibration line on the neck of the flask.

g. The outside of the flask is cleaned and any moisture adhering to the inside of the bottle neck above the calibration line is removed.

h. The flask and contents are weighed to the nearest 0.01 gram, and the weight recorded as $W_b$.

i. The temperature, $T_x$, of the suspension to the nearest $0.1^oC$ is obtained.

j. The weight of the bottle filled to the calibration line with distilled water only, $W_a$, is determined from the calibration curve for the particular flask in use. $T_x$ is used as the entry parameter for the curve.

k. The specific gravity of the sample, based on water at temperature $T_x$, is calculated using:

$$G_s\left(\frac{T_x}{T_x}\right) = \frac{W_o}{W_o + (W_a - W_b)} \qquad (2)$$

The results of equation (2) are multiplied by the relative density of distilled water at temperature $T_x$ to obtain the specific gravity relative to distilled water at $4^oC$. Equation (2) then becomes:

$$G_s\left(\frac{T_x}{4^oC}\right) = \frac{W_o D_x}{W_o + (W_a - W_b)} \tag{3}$$

where $D_x$ is the relative density of distilled water at $T_x$. Tables of the relative density of water for various temperatures are available in handbooks.

5. <u>Discussion of the Bottle Pycnometer Method</u>

The primary advantage of this method is its acceptance as the standard procedure for the specific gravity determination of both terrestrial and marine soil particles. The great majority of specific gravity determinations have been made by this method. The technique is highly repeatable for the same material if sufficient care is paid to the drying method, weighing technique, visual estimate of the bottom of the meniscus at the calibration mark, and procedure for air removal.

It is generally recognized that incomplete air removal from the suspended matter is the most common error associated with this procedure. If excess air bubbles remain in the suspension, the computed specific gravity value will be lower than the true value. In order to determine if the sample is sufficiently de-aired, the valve on the vacuum line to the flask is closed, and the stopper on the flask is slowly removed while observing the water level in the neck of the flask. If the water surface is lowered less than one-eighth inch for a standard 500 milliliter volumetric flask, the sample is considered adequately de-aired.

The specific gravity computation equation involves a difference in weights which is small in comparison to the weights themselves; hence, inaccurate weight values can produce errors in specific gravity results. Sources of improper weights stem from (1) imprecise weighing of flask, water, and sample; (2) unclean flasks; (3) moisture on the outside of the flask or on the inside of the neck; and (4) improper visual setting of the meniscus at calibration line. If the material is boiled while vacuum is applied, some of the sample may possible be lost if the procedure is not closely monitored. If the temperature of the flask and contents is not uniform, an unrepresentative temperature may be obtained which would affect the results.

The biggest disadvantage of this method is the time required to complete the analysis. After the sample is dried for twelve hours, an additional twelve hours of soaking in distilled water is required prior to air removal. If the boiling technique is utilized for air removel, an overnight cooling period is necessary prior to weighing the flask and contents. Soil mechanics procedures usually recommend two to four hours as a minimum for de-airing by evacuation. Some investigators have found that additional evacuation in excess of 24 hours is necessary for accurate results. These requirements turn the specific gravity determination into a three day procedure.

<u>Air Comparison Pycnometer</u>

The Beckman Model 930 Air Comparison Pycnometer [Beckman Instruments, Inc., 1965] is a manually-operated device designed to measure the volume of powdery, granular, porous and irregularly-shaped solids. The instrument measures the true volume of the solid portion of a sample and excludes pore openings. Volume determinations of particulate matter up to 50 cubic centimeters can usually be made by an experienced operation with repeatability of better than $\pm$ 0.05 cubic centimeters. The weight of the sample can be obtained by standard methods to provide the other value necessary for the specific gravity determination.

1. Principle of Operation

Figure 2 is a schematic drawing of the Beckman Air Comparison Pycnometer. The instrument basically consists of two cylinders and two pistons with interconnecting piping, valves, and a differential pressure indicator. The reference cylinder contains two positive stops for the reference piston. A digital counter to indicate the sample volume is connected to the measuring piston. The measuring cylinder is connected to the sample container.

When the coupling valve is closed and the sample cup locked in place, the differential pressure indicator indicates the difference in pressure between the measuring and reference cylinders. In this condition, and with no sample in the cup, any movement of one piston must be accompanied by a movement of identical stroke on the other piston to maintain a null reading on the differential pressure indicator. If both pistons are positioned in the forward position and advanced simultaneously until the reference piston is against the rear stop, the counter should indicate zero volume. If this procedure were repeated with a sample of some volume, $V_x$, in the cup, and the pistons advanced the same distance, the pressures in the two cylinders would not be the same. A null pressure differential could be obtained by withdrawing the measuring piston some distance, $d_x$. This distance, $d_x$, is related to the volume, $V_x$, and is calibrated so as to read the volume directly in cubic centimeters on the counter.

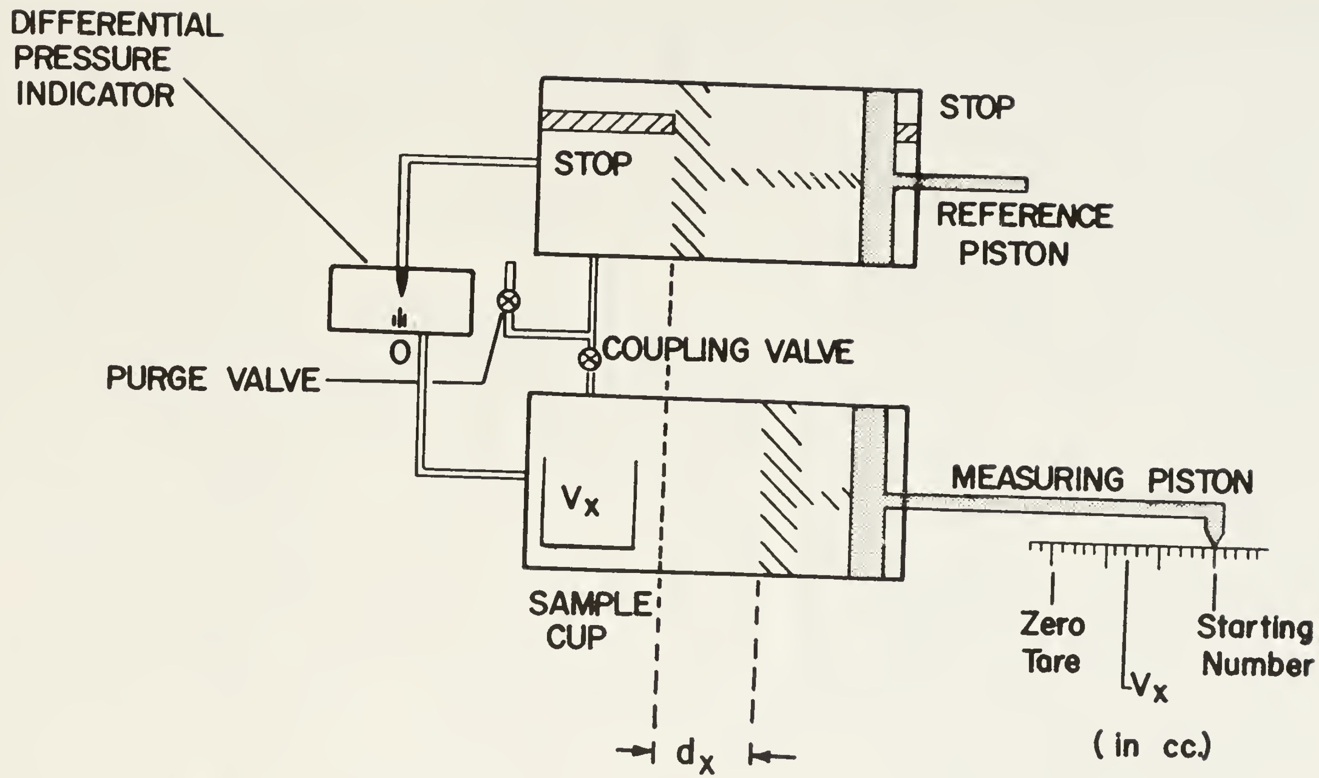


Figure 2. Schematic of Beckman Model 930 Air Comparison Pycnometer.

Figure 3 is an end view of the instrument showing the piston handwheels, helium purge manifold, sample cup and calibration balls. Use of the three-valve manifold will be described later. The calibration balls have volumes known to $\pm$ 0.015 cubic centimeters and are used to teach operators and check the calibration of the instrument. Figure 4 is a view of the sample cup compartment. Figure 5 shows the differential pressure indicator and the volume digital counter.

2. Modes of Operation

Three basic modes of operation are available depending upon the characteristics of the material to be measured. The pycnometer uses air as the gas for volume determinations of non-surface active, non-compressible materials. The air is initially at a pressure of one atmosphere and as the pistons are advanced the air is compressed to two atmospheres. A second operating mode is designed for compressible materials. Again the initial pressure of the air is one atmosphere. The pistons are initially advanced to the expected volume of the sample. After the sample cup is locked in place the pistons are withdrawn to their normal starting position thus reducing the pressure to one-half atmosphere. The determination is completed in the normal manner thereby increasing the pressure back to one atmosphere.

A third operating mode incorporates the use of the inert gas, helium, for the volume measurement of surface-active materials. These materials usually give values lower than the true volume. This is caused by the absorption of the constituents of air by the surface-active materials.


Figure 3.  End View of Air Comparison Pycnometer showing Handwheels.


Figure 4. End View of Air Comparison Pycnometer showing Sample Cup Compartment.

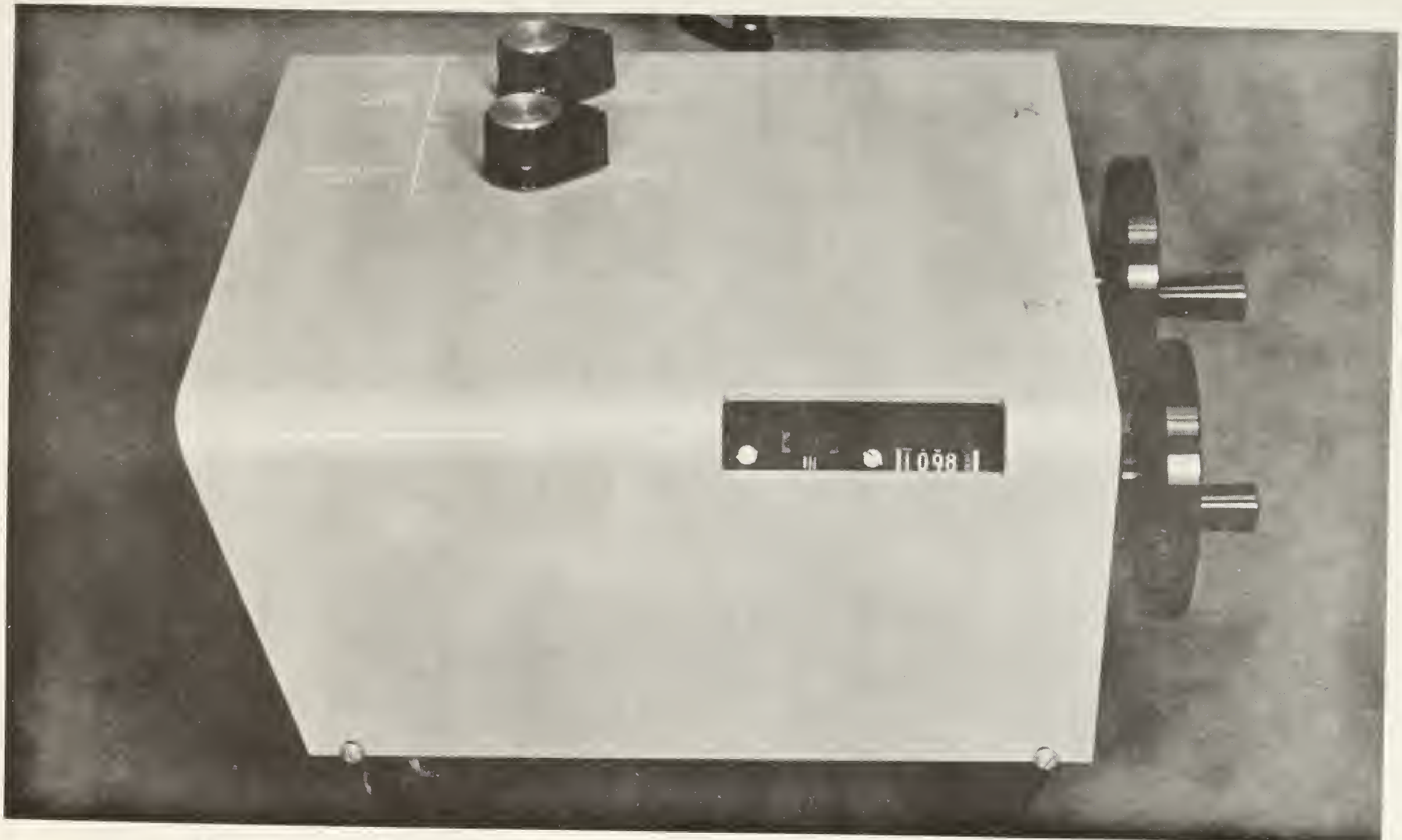

Figure 5. Side View of Air Comparison Pycnometer showing Differential Pressure Indicator and Digital Volume Counter.

### 3. Operating Procedures

The following three procedures were used in a comparison test to be discussed later. The helium (1-1/2-1 atmospheres) procedure is a combination of two of the basic operating modes.

a. Air Procedure (1-2 atmospheres)

(1) Initially a zero measurement check is conducted. The procedure is identical to the measurement procedure, but a clean and empty sample cup is used. If the result of this check is other than zero, a second zero measurement check is made to verify the zero off-set. Once a zero off-set value is established, it is used as a tare number to correct subsequent volume determinations. A tare number greater than zero is subtracted from subsequent determinations, and a tare number less than zero is added.

(2) The purge valve is closed, and the coupling valve is opened.

(3) The piston handwheels are rotated to their counter-clockwise extreme positions.

(4) The measuring handwheel is turned clockwise until the starting number is set on the counter. This is a calibrated starting position for the measuring piston that allows full stroke on the measuring piston to equal full stroke on the reference piston.

(5) The sample is placed in the cup and the cup firmly locked in the sample cup compartment.

(6) After a 15 second wait to equalize pressures between the two cylinders the coupling valve is closed.

(7) Both handwheels are simultaneously turned clockwise until the reference handwheel rests against its stop. The differential pressure indicator is kept on the scale during this process.

(8) After a 10 second wait the pointer on the differential pressure indicator is brought to the null position by turning the measuring handwheel only.

(9) The coupling valve is opened while noting the position of the differential pressure pointer. If the pointer does not shift as the valve is opened, a true null was obtained and the sample volume is read directly from the digital counter. If the pointer shifts, the run should be repeated.

(10) Both handwheels are turned counterclockwise to rest against the stops. This step is essential to reduce the system pressure from two atmospheres to one atmosphere. If the cup were released prior to this step, the sample would be blown out of the cup due to the excess pressure in the system.

(11) The sample cup is removed, and the pycnometer is now ready for another determination starting with step (3).

b. Helium Purge Procedure (1-2 atmospheres)

(1) The three-valve manifold is mounted on the air comparison pycnometer as shown in Figure 3. The manifold gas valve is connected to the helium tank regulator and the vacuum valve to the vacuum pump. The helium regulator is set for 2 psig inlet pressure.

(2) A zero measurement check is made to establish a tare number. This check is run using the helium purge procedure instead of the air procedure.

(3) The measuring and reference piston handwheels are rotated to their counterclockwise extreme position.

(4) The measuring handwheel is turned clockwise until the starting number is set on the counter.

(5) The sample is placed in the cup and the cup is locked firmly in its compartment.

(6) The purge valve and then the coupling valve are opened.

(7) The manifold vacuum valve is opened and the system is evacuated to the desired pressure. After evacuation is completed, the vacuum valve is closed.

(8) The gas valve is opened for at least 5 seconds to allow the helium to purge the system. The gas valve is then closed.

(9) The vent value is opened for 5 seconds to vent the system to the atmosphere. The vent valve and then the purge valve are closed.

(10) The coupling valve is closed after waiting 15 seconds for pressure equilibration between the two cylinders.

(11) Both handwheels are turned clockwise simultaneously until the reference piston rests against its stop. The differential pressure pointer is kept on its scale during this process.

(12) After at least a 10 second wait, the pointer is brought to the null position by turning the measuring handwheel only.

(13) The coupling valve is opened while observing the differential pressure pointer. If the pointer shifts position, a true null was not obtained and the run should be repeated. If the

pointer did not shift, the sample volume is read on the counter directly in cubic centimeters.

(14) Both handwheels are turned counterclockwise to rest against their stops.

(15) The sample cup is removed and a new volume determination may be started with step (4).

c. Helium Purge Procedure (1-1/2-1 atmospheres)

(1) The three-valve manifold is mounted on the air comparison pycnometer, the gas valve is connected to the helium tank regulator, and the vacuum valve is connected to the vacuum pump. The helium regulator is set for 2 psig inlet pressure.

(2) A zero measurement check is conducted to establish a tare number.

(3) The reference handwheel is rotated clockwise to its forward stop.

(4) The measuring handwheel is turned to the estimated sample volume.

(5) The sample is placed in the cup and the cup is firmly locked in place.

(6) The purge valve and then the coupling valve are opened.

(7) The vacuum valve is opened to allow the system to evacuate and the valve is closed after approximately 15 seconds.

(8) The gas valve is opened for about five seconds to allow the helium gas to fill the system and then the valve is closed.

(9) The vent valve is opened for about five seconds to vent excess pressure to atmosphere. The vent valve and then the purge valve are closed.

(10) The reference handwheel is rotated counterclockwise to its rear stop. The measuring handwheel is rotated counterclockwise to a point beyond the starting number and then clockwise to the starting number. The system pressure is now approximately one-half atmospheric pressure.

(11) After a ten second wait for pressure equilibration between the two pistons, the coupling valve is closed.

(12) Both handwheels are turned simultaneously until reference handwheel rests against its stop. The differential pressure pointer is kept on scale during this process. System pressure is again at one atmosphere.

(13) After a 10 second wait, the pointer is brought to the null position using the measuring handwheel only.

(14) The coupling valve is opened while checking for a shift of the differential pressure pointer. If the pointer remains steady, a true null was obtained and the volume can be read on the digital counter.

(15) The sample cup is removed and another determination is commenced at step (4).

4. Discussion of Gas Pycnometer Method

The primary advantage of the air comparison pycnometer is the rapidity of the volume determination. A maximum time of five minutes is required per determination regardless of the procedure used. The sediment sample is usually oven dried for twelve hours at $105^{o}C \pm 5^{o}C$ and then ground in a mortar and pestle to a fine powder. The device is simple to operate and only requires that the operator familiarize himself with its characteristics to gain a feel for when the reference piston is against the stop in either direction. The equipment is portable and could be used at sea. If the problem of weighing while aboard a ship at sea is solved, the pycnometer could be readily utilized in a sea-going laboratory to determine specific gravities.

The air comparison pycnometer is somewhat temperature sensitive, and should be in approximate temperature equilibrium with its surroundings. Both the sample and sample cup should be within $5^{o}F$ of instrument temperature. This requires the cooling of the sample to room temperature after the drying procedure.

The two most common sources of error in volume determinations are failure to firmly lock the sample cup in place and excessive temperature differential between the sample and the system. Both sources of error are evidenced by a drifting differential pointer at the end of the run. Extreme cases are easy to distinguish, but a slight leak or small temperature differential is difficult to distinguish from needle drift due to surface activity of the sample.

Jolly Balance

The Kraus Jolly Balance, shown by Figure 6, is a hydrostatic weighing instrument requiring only two readings and a single division to compute specific gravity [Kraus, Hunt, and Ramsdell,

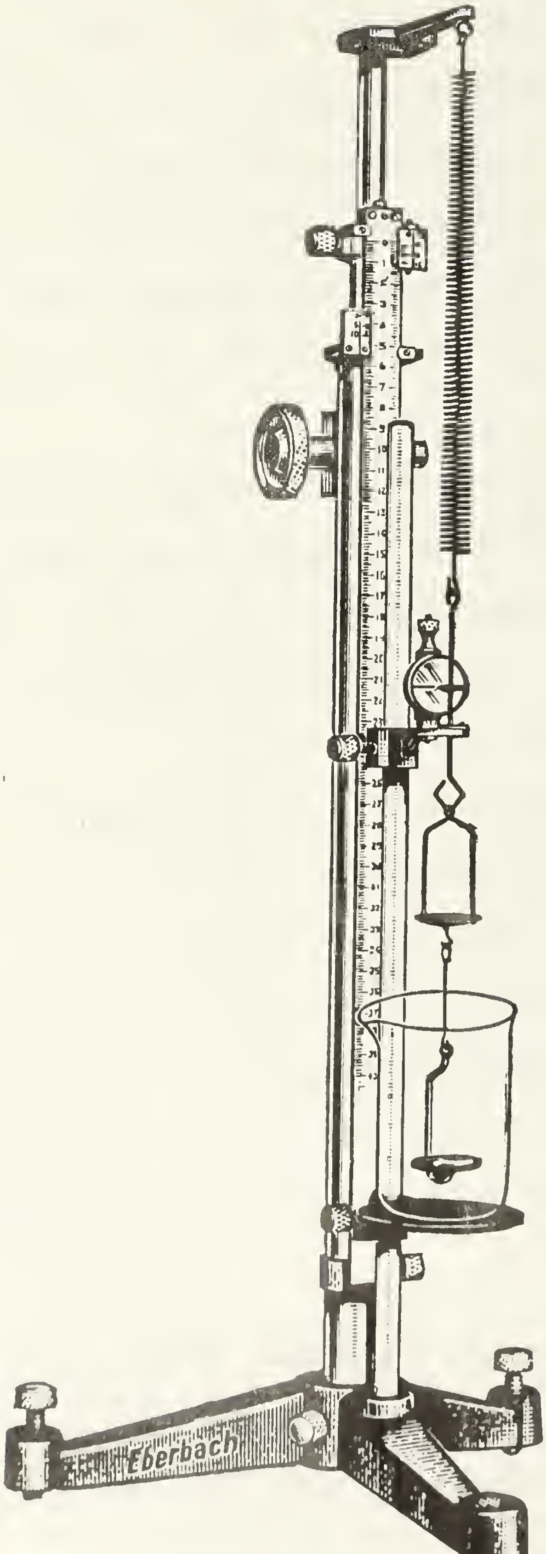

Figure 6. Kraus Jolly Balance

1951]. One reading is made with the sample in air, and the second reading is made with the sample immersed in water. The balance consists of a single spring attached to a movable tube, which also carries a doubly graduated scale. The left-hand and right-hand scales are read using their verniers. In the determination procedure the left-hand scale indicates movement of the scale to compensate for spring elongation due to the sample being placed on the upper pan. The right-hand scale indicates scale movement to compensate for spring contraction when the sample is immersed in the fluid on the lower pan. Two springs, light and heavy, are utilized with the instrument.

1. <u>Determining Proper Spring to Employ</u>

The sample weight is determined to the nearest gram. The light spring is used as supplied for samples weighing between one and ten grams. For a sample weighing between ten and twenty grams, cut off a portion of the spring until a maximum elongation of 40 centimeters is reached with a load of 22 grams. The heavy spring is used as supplied with a sample weight between twenty and fifty grams. For a sample weighing between 50 and 100 grams, trim the length of the spring until a maximum elongation of 40 centimeters occurs with a load of approximately 100 grams.

Basically the determination should be performed with the spring near the point of maximum elongation for greatest accuracy and reproducibility of results.

2. Sample Preparation

The sample is first oven dried at $105^{o}C \pm 5^{o}C$ for twelve hours, and then allowed to cool to room temperature in a desiccator. Sediment samples should be ground to a fine powder in order to remove impermeable void spaces.

3. Specific Gravity Determination Procedure

Initially the two verniers and double scale are adjusted to a zero reading at the top of the instrument. A beaker of suitable size, usually 100 to 250 milliliters, and filled with distilled water is placed on the support shelf. The appropriate spring is suspended from the over-hanging support arm with the index rod and reading disk, metal pan, and glass pan attached in that order. The glass pan is immersed in the water by adjusting the beaker support shelf until the metal pan is one to two inches above the water level. Further zeroing is accomplished at this point to ensure the index disk is lined up with the horizontal mark on the mirror. Coarse adjustment is accomplished by raising or lowering the mirror support on its support rod. Fine adjustment is made by manipulation of the adjusting screw on top of the mirror. The instrument is now ready for a specific gravity determination using the following procedure.

a. The sample is placed on the upper metal pan. By means of the large handwheel on the left hand side of the instrument, the scale is moved up until the index disk is in line with the mirror, as indicated in Figure 6.

b. The weight of the sample in air is obtained by reading the left-hand scale from the top down, employing the fixed vernier.

c. The scale is then clamped by means of the knurled knob on the lower right-hand side of the instrument.

d. The sample is moved to the lower glass pan by lowering the beaker, transferring the sample, and raising the beaker until the metal upper pan is approximately 1-1/2 inches above the water level. It is important that no air bubbles remain attached to the sample or pan.

e. The large handwheel is turned clockwise, thus lowering the scale until the index disk is coincident with the line on the mirror.

f. The second reading required is now made on the right-hand scale using its vernier. The reading represents the loss of sample weight when immersed in the water.

g. The specific gravity is calculated by dividing the weight in air determined in step b. by the loss of weight from step f.

4. Discussion of Jolly Balance Method

Specific gravity determination by this method is quick and easy. Other fluids more compatible than water with the material to be tested may be used. This instrument was compared with the Beckman Air Comparison Pycnometer by McIntyre, Welday, and Baird [1965]. The material used for the evaluation was granite rock. In that study specific gravities of 30 coherent rock specimens were determined in duplicate by both air pycnometer and Jolly balance, and a statistical analysis was performed on the results. Standard deviations were 0.0057 and 0.011 for the Jolly balance and air pycnometer, respectively. In that samples of only six to ten cubic centimeters were used, the evaluation was biased in favor of the Jolly balance. The full length of the Jolly scale was used, while the air pycnometer, with a sample cup capacity of 50 cubic centimeters, operated at less than one-quarter of its theoretical capacity.

Further evaluation of the air pycnometer was conducted utilizing larger sample sizes, and it was concluded that the air pycnometer was superior to the Jolly balance if larger sample sizes were utilized in the air comparison pycnometer.

The Jolly balance is primarily used by geologists and mineralogists to determine the specific gravities of fragments and chips of minerals or coherent rocks. The procedure does not appear compatible with the analysis of fine particulate matter as no provision is made for the removal of air from the sample when immersed in the fluid.

Berman Density Balance

The Berman Density Balance shown in Figure 7 consists of a sensitive torsion balance equipped with special accessories for the rapid measurement of specific gravity. The instrument uses the hydrostatic weighing principle and can be read to the nearest 0.01 milligram. The range of the balance is zero to 25 milligrams with no counterweight on the counter-weight arm. The addition of a 25 milligram weight on the counter-weight arm will result in a range of 25 to 50 milligrams. A maximum weight of 75 milligrams may be attained with the use of counter-weights.

A weight determination is made by suspending the sample from the balance arm. Two devices for holding samples are also shown in Figure 7. The double weighing pan is made of very fine platinum wire and has an upper platform pan for weighing the sample in air. Below the pan is

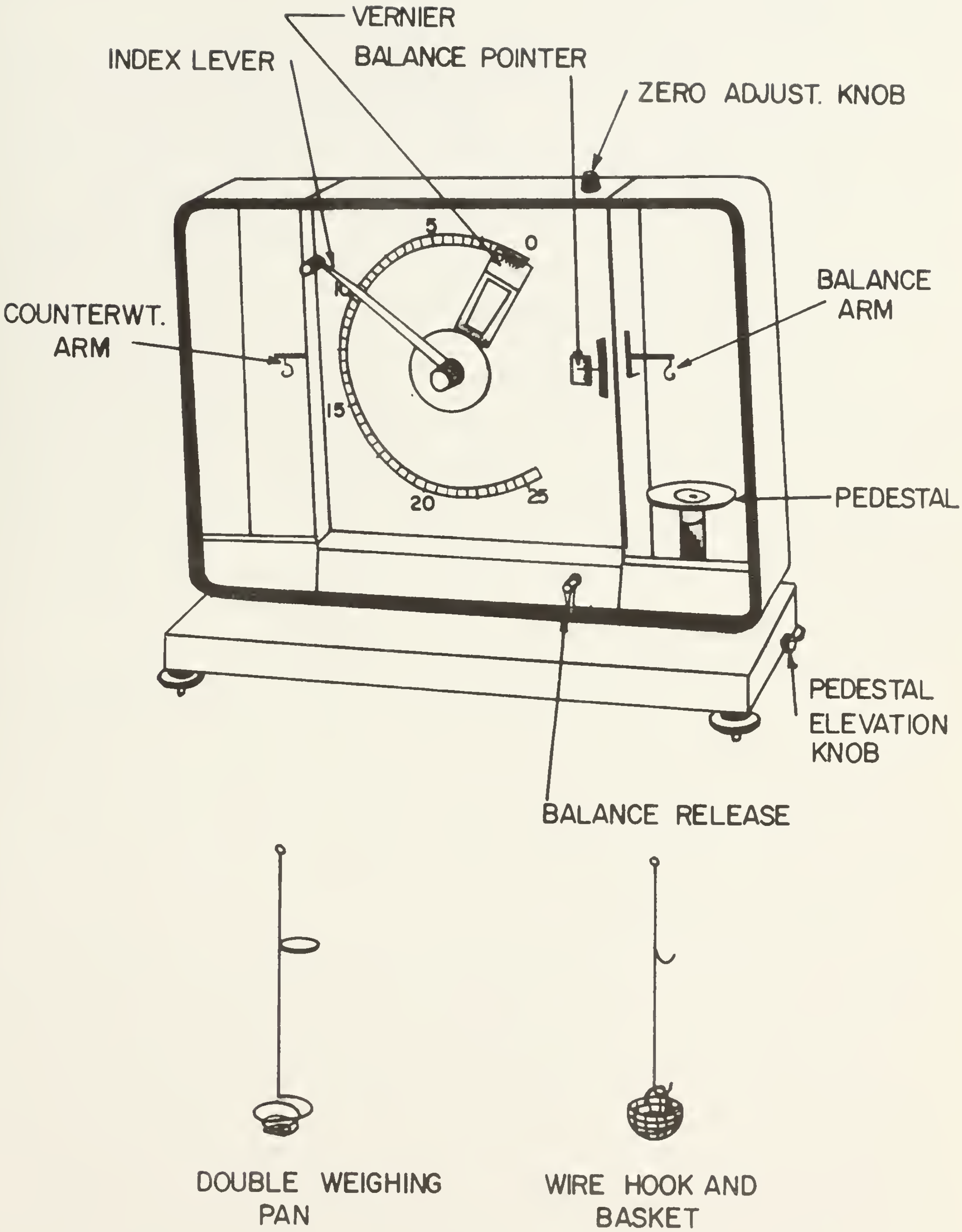


Figure 7. Berman Density Balance

a coiled helix to hold the sample for immersed readings. For weighing many small mineral fragments the wire hook and basket is used. The basket is made of 220-mesh screening and is hung on the lower or upper hook for weighings in or out of the fluid, respectively.

The liquid is held in a small glass beaker on the pedestal and may be elevated or lowered by the pedestal elevation knob. Water, toulene, or any other fluid suitable for the sample being weighed is used. Toulene is preferred over water because of its lower surface tension.

1. Sample Selection and Preparation

The optimum sample weight to be used with the Berman Balance is between 15 and 25 milligrams. The accuracy of measurement decreases rapidly for samples weighing less than 10 milligrams. Samples over 25 milligrams require the addition of a counterweight to extend the range of the instrument. Larger sample weights also result in a loss of accuracy, especially those in excess of 50 milligrams.

Particular care must be exercised in selecting the sample. Single grains should be used if possible. Coarse powders can be measured using the fine mesh basket. If possible, the sample should be washed in the immersion fluid prior to testing.

2. Balance Preparation

An initial zero adjustment must be made with the sample holder suspended from the balance arm and immersed about half-way in the fluid.

The balance arm is released by turning the balance release to its horizontal position. The index lever is adjusted until the zero on the vernier coincides exactly with the zero on the dial. The balance pointer, which is attached to the balance arm, should coincide with its zero line. If it does not, the zero adjust knob is used to bring the pointer to zero. The balance pointer swings in front of a small mirror, and for a perfect zero adjustment the pointer, its image in the mirror, and the zero line must all coincide exactly. When this alignment is accomplished, the beam is in balance and ready for use.

3. Specific Gravity Determination

While the balance release lever is in the locked position, the sample is placed on the upper pan by allowing it to slide from a V-shaped piece of paper. The balance arrest mechanism is then released slowly to ensure that the hanger does not dip abruptly into the liquid. When the balance is fully released the sample weight is determined in air. At this time the lower pan is immersed in the liquid. For consistent results it is useful to bring the lower pan to the same depth in the liquid for every reading. This cancels surface tension effects and the weight of the immersed wire.

To transfer the sample to the lower pan, the balance is arrested and the sample hanger removed from the hook with tweezers. The level of the liquid should not be changed. Using a needle or other small implement the sample is moved from the top pan onto a piece of paper and then allowed to slide into the lower basket. The hanger should be held vertically with the lower container just touching the surface of the table for support. The hanger is replaced on the balance arm hook, the balance is released, and the sample weight in the liquid is read on the vernier. Specific gravity is then calculated by dividing the weight of the sample in air by the loss of sample weight in the fluid with correction factors applied for the density of fluid used and the fluid temperature.

4. Discussion of Berman Density Balance Method

The Berman Density Balance technique is simple and rapid. A specific gravity determination may be conducted in five minutes. Berman [1939] reported the obtainable accuracy is 0.2 percent with a 25 milligram specimen of specific gravity of 5. Using a large number of fragments of total weight of 25 milligrams, specific gravity five, and weighing in a basket, the accuracy is reduced to one percent.

The instrument is not considered adequate for specific gravity determinations on marine sediments because of (1) the small sample size, and (2) the lack of provision for de-airing the sample. A three inch interval of a core sample two inches in diameter weighs well in excess of 100 grams. A 25 milligram specimen of this core sample would, in all probability, not be representative of the specific gravity of the core interval. A sample of fine particulate matter might fall through a wire mesh basket when immersed in the fluid. A solid container would allow the entrapment of air in the sample as the container is immersed. Either occurrence for the small sample weight used with this instrument would give an erroneous reading for fine particulate samples.

Differential Gravity Tube

A differential gravity tube is a mixture of two fluids in a column whose specific gravity varies from top to bottom. The fluids are commonly known as heavy liquids. Heavy liquids have been used for many years as a means of mineral separation or ore dressing. Their use for specific gravity determination is an application of the flotation method. The initial employment of this method consisted of adding an unknown sample to a liquid of known specific gravity. According to whether the sample sank or floated the solution was either diluted or concentrated by adding another liquid until the sample assumed a position of hydrostatic equilibrium in the mixture. At that time the specific gravity of the sample is the same as that of the fluid and the specific gravity of the fluid mixture was determined by other means. Centrifugation was used to accelerate this process. (See Shapiro [1969] for an application using centrifugation.) The specific gravity gradient column has developed from the original use of the sink or float test.

1. Preparation of Tube for Use

A differential gravity tube is formed by the incomplete mixing of two miscible heavy liquids of different specific gravities in a graduated cylinder or burette. The choice of heavy liquids for use in the tube varies according to the range of specific gravities expected in the materials to be tested. Some typical heavy liquids are acetylene tetrabromide, bromobenzene, methylene iodide, and thallium malonate-formate. The best method for mixing the heavy liquids, according to Canada and Laing [1967] is to introduce the heavier liquid at a constant flow rate into a mixing chamber containing the lighter liquid and letting the mixture of increasing specific gravity flow into the gradient tube. The gradient will be linear if the flow rate into the gradient tube is twice the flow rate of the heavier liquid into the mixing chamber.

Small calibration floats are used to establish the characteristics of the gradient. These reference floats may be obtained with a specific gravity accurate to four decimal places. The reference floats are added to the column, and when they reach hydrostatic equilibrium their position is precisely measured. A calibration curve is prepared plotting specific gravity versus depth in column by means of the reference floats.

2. <u>Specific Gravity Determination</u>

The sample material is added to the column and when it reaches its equilibrium position, its depth in the column is precisely measured. The intersection of this depth with the reference standard calibration curve then indicates its specific gravity.

3. <u>Discussion of the Differential Gravity Tube Method</u>

The stability of the specific gravity gradient established in the column is dependent on the diffusion rate of the heavy liquids used, frequency of use, and the agitation of the column created by adding samples or clearing the column. With proper care and temperature control the column may be expected to maintain a closely linear gradient in excess of two months.

This particular method is simple to apply, and the time required for a determination depends primarily on how fast the sample reaches its equilibrium position. Accuracy depends on the range of the specific gravity differential in the column, the age of the column, and the means used to measure the position of the samples in the column. The method is applicable to the specific gravity determination of individual small particles. Sediments and soils are aggregates of minerals having a variety of specific gravities. The constituents of a sample of fine-grained, powdered, marine sediment would spread throughout the column, with each constituent seeking its equilibrium position. The required weighted average of the specific gravities of the particular mineral assemblege in the sample is not directly provided by this method. It is also recognized that a small specimen is not representative of the specific gravity of considerably larger samples. For these reasons, the flotation method, in general, is not suitable for the specific gravity determination of marine sediments.

Derived Equation for Specific Gravity Computation

From the basic definitions for water content and bulk wet density equation (4) was derived for the computation of specific gravity.

$$G_s = \frac{BWD}{1 + WC - (BWD \times WC)} , \tag{4}$$

$G_s$ = specific gravity of solids,

WC = water content (percentage),

BWD = bulk weight density (grams per cubic centimeter).

It was assumed for the derivation that the water evaporated from the sample during the water content determination is salt-free with a specific gravity of one. A correction for dissolved solids from the sea water remaining in the sample after evaporation was considered to be negligible for the purpose of applying this equation. The complete derivation of equation (4) is shown in Appendix C.

Two sets of data containing values of water content, bulk wet density, and specific gravity were obtained to determine the validity of equation (4) as a means of obtaining an accurate value of specific gravity of solids. The first set was secured from the Naval Civil Engineering Laboratory, Port Hueneme, California, and pertains to 42 cores collected from the Eastern Pacific Ocean and analyzed during

1963 and 1964. Water content was determined by obtaining a quantity of the sample in a cylinder of known weight and determining the weight of the wet sample. The dry weight was determined after the sample was oven dried over night at 100$^{o}$C and cooled in a desiccator. Water content was then computed by dividing the weight of the water by the weight of the solids. Bulk wet density was determined by using a small cylinder of known volume and determining the weight of the undisturbed wet sample necessary to fill it. The bulk wet density was then computed by dividing the wet sample weight by its volume. The specific gravities for this same material were determined with a Beckman Air Comparison Pycnometer using helium as the comparison medium.

A computer program was written to calculate the specific gravity using equation (4) and to compare these computed values with those determined by the air comparison pycnometer. A difference representing the gas pycnometer value minus the calculated was computed and recorded. The computer program is contained in Appendix D.

Fifty-six percent of the computed specific gravities were greater than the air comparison pycnometer values for the 386 intervals from these cores. In general it may be noted that the comparison was very poor, with only 10 percent of the computed values agreeing to within $\pm$ 0.05 of the pycnometer values. The computer output for the Naval Civil Engineering Laboratory data is included in Appendix E.

A second set of data, obtained from Technical Report Number 106 of the U. S. Naval Hydrographic Office by Richards [1962], was treated in a similar manner. The water content and bulk wet density were determined using essentially the same techniques as were used for the

NCEL data. Specific gravities were measured by the bottle pycnometer method using 100 milliliter flasks. Some 180 intervals of sixteen cores from this data were subjected to the computer program. Thirty-two percent of the specific gravities computed by (4) were greater than the bottle pycnometer values. Forty-five percent of the calculated specific gravities agreed within $\pm$ 0.05 of the bottle pycnometer values. The computer output for the Hydrographic Office data is included in Appendix F.

Equation (4) was derived to make possible the use of water content and bulk wet density values, which are routinely determined during the physical processing, to calculate specific gravity easily. This would thereby eliminate the need for the questionable and time-consuming specific gravity determination. The results of this investigation of the two sets of data indicate that accurate specific gravities, as compared to actual determinations by either bottle pycnometer or gas pycnometer, are not attainable by equation (4). The probable causes for the inadequacies of this calculation are inaccuracies in the techniques for the determination of water content and bulk wet density.

# IV. COMPARISON OF AIR COMPARISON PYCNOMETER AND BOTTLE PYCNOMETER METHODS

## General

The general acceptance of the bottle pyncometer as a standard method for specific gravity determination for sediments has been cited previously along with the advantages and disadvantages of the procedure. The time reduction per specific gravity determination offered by the gas pycnometer warranted an evaluation of the device in comparison with the bottle pycnometer. There have been numerous articles published that evaluate the characteristics of the gas pycnometer (Beckman Instruments, Inc. [1960], Joyce [1961], Meinhall and Buckingham [1962], Landy and McGahan [1963], Price [1964], Mitchell [1964] and Tuul and DeBaun [1962]). However, the majority of these have used air as the comparison medium with only two using helium in their tests.

For the above reason, three operating modes of the gas pycnometer, two of which use helium, were compared with results of the bottle pycnometer method. The gas pycnometer modes tested were the air (1-2 atmospheres) procedure, the helium (1-2 atmospheres) procedure, and the helium (1-1/2-1 atmoshcres) procedure. Inclusion of the helium tests was considered necessary in view of the need for a means of accurate volume determination of colloidal materials. Figure 8 is a picture of the laboratory equipment used for the bottle pycnometer tests. Figure 9 shows the air comparison pycnometer with the vacuum pump and helium tank attached to the helium purge manifold via plastic tubing.

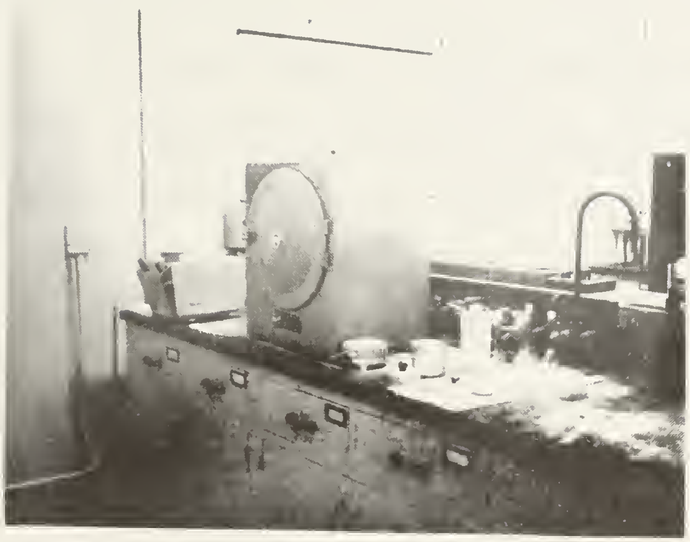

Figure 8. Equipment Used for Bottle Pycnometer Determinations

Figure 9. Air Comparison Pycnometer with Vacuum Pump, Helium Bottle and Regulator

A similarity between the earlier gas pycnometer evaluations noted above was their common use of a comparison technique in which a specific gravity value measured by one technique was compared with another value for the same sample found by a second technique. Such testing on a one for one comparison basis does not provide sufficient repetition to reveal an error in either of the techniques for any one test material under observation. In addition it does not permit the establishment of a mean value and variation for the compared techniques, whereby the accuracy and precision of the methods may be established. Statistical analysis using analysis of variance techniques as discussed in Ostle [1963], provides a sound basis for comparing two or more methods and hence was chosen to compare the bottle and gas pycnometers. The BIMED Analysis of Variance for One-Way Design was used as the statistical analysis tool. This computer program is the version of June 15, 1966, developed by the Health Services Computing Facility at the University of California at Los Angeles [Dixon, 1968]. The statistical analysis procedure required the determination of a specific gravity value using each of the three gas pycnometer modes and also the bottle pycnometer method for a number of samples of each test material. The number of samples of each test material required was chosen to obtain an adequate number of degrees of freedom to ensure a low critical F-ratio. A low critical F-ratio ensures less chance of rejecting the null hypothesis for the experiment if the null hypothesis is actually true. The null hypothesis applied to each test material was that there is no significant statistical difference between the specific gravity values determined by the three gas pycnometer modes and the bottle pycnometer method.

It was desired to obtain test materials with an established specific gravity that exhibited the colloidal properties of marine sediments. A quantity of material with consistent constituents was required such that replicate determinations could be made on a number of samples for statistical analysis purposes. The analysis of variance technique requires the assumption that the samples chosen from a quantity of test material be consistent. The selection and preparation of the sample material was designed to meet this requirement.

Suitable test material, having specific gravity values known to three decimal places, was not readily available. As a consequence, quantities of the American Petroleum Institute reference clay samples were procured for test purposes. Kaolinite (A. P. I. reference clay #4) and montmorillonite (A. P. I. reference clay #25) were selected because of their reported purity and differing physical and chemical characteristics. These clay minerals are two of a group of selected clay samples collected at the same localities in the United States from which the original reference clay samples were obtained that served as the basis for American Petroleum Institute Clay Mineral Standards Project No. 49. The identity of these clays with original A.P.I. clay mineral standard specimens had been previously established for the commercial source by direct comparison of X-ray diffraction and differential thermal analysis data on the new material and the original standards.

In that the true specific gravities of the kaolinite and montmorillonite clay samples were unknown except for reported values of comparable materials found in other literature, crystalline quartz was used as an established reference standard. The specific gravity values of quartz at various temperatures has been summarized by Frondel [1962]. Tests were run on the quartz material in the same manner as for the reference clay samples and the results were statistically analyzed.

An additional comparison of the gas pycnometer and bottle pycnometer was made using alternate four inch intervals of a fifty inch sediment core. Although statistical analysis is not applicable to these results, individual comparisons for the eight intervals tested could be made.

Sample Preparation

The sample materials were prepared for testing with a consideration for the requirements of both the gas pycnometer and bottle pycnometer procedures and the need for homogeneous samples for valid statistical analysis. The kaolinite was received in the form of large dry lumps. Approximately 500 grams were hand-ground in a ceramic mortar and pestle to a very fine powder, and then divided into ten samples of 50 grams each, which were oven dried at $105^{\circ}C \pm 5^{\circ}C$ for twelve hours. The samples were then placed in a desiccator and cooled to room temperature prior to testing.

The montmorillonite contained some of its natural moisture and hence was oven dried for six hours prior to grinding. Approximately 500 grams of the pre-dried material were then ground, divided, oven-dried, and cooled in a desiccator in the same manner as the kaolinite.

The quartz was received in the form of crystals measuring approximately one by one by two inches. An attempt was made to use only the optically pure tips of the large cyrstals by crushing them into smaller pieces and selecting the desired fragments. These fragments were then crushed into small chips using the cup and piston shown in Figures 10 and 11, and then placed in a ball mill for reduction to a coarse powder. Final grinding was done in either an automatic or manual mortar and pestle. After each phase of crushing or grinding, a magnet was used to remove metal fragments introduced by the crushing process. The powder was then sieved and 540 grams of quartz powder were collected that had passed the #230 sieve. This quartz powder was then divided into 12 samples of 45 grams each, oven-dried, and cooled in the same manner as the reference clay samples.

Because the sediment core contained its original water content, it was pre-dried 18 hours prior to being ground into a fine powder. Fifty grams of each of the eight intervals were then oven-dried and cooled as were the previous samples.

Additional drying of the montmorillonite and sediment core materials after the pre-drying and grinding was considered necessary in order to reduce the possibility of biasing the gas pycnometer determinations. Fine-grained dry colloidal material tends to absorb moisture from the atmosphere. Numerous checks were made on the weight of kaolinite and montmorillonite after 10 to 15 minutes of exposure to the atmosphere. These checks indicated a weight increase of approximately 0.01 grams for a 40 gram sample in every case. Exposure of the samples to the atmosphere for an extended time could alter the specific gravity values. As a consequence all samples were dried for 12 hours after being ground and prior to their analysis.

Figure 10. Quartz Crushing Apparatus

Figure 11. Quartz Crusher Components

## Specific Gravity Results for Kaolinite

### 1. General

Kaolinite is a clay mineral having the general formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ in which the Al to Si ratio can vary from 2:1 to 3:1. It is a two-layer clay thereby composed of a single sheet of silica tetrahedrons and a single sheet of alumina octahedrons combined so that the tips of the silica tetrahedrons and one of the layers of the octahedral sheet form a common plane. Kaolinite single crystals have a ratio of areal diameter to thickness of from 2:1 to 25:1. Widths of 0.05 to 2.11 microns and lengths of 0.07 to 3.51 microns are common [Kerr, et al., 1951].

### 2. Results

The results of the specific gravity determinations on the ten kaolinite fractions are shown in Table I.

An observed F-ratio of 167.99 as computed by the BIMED analysis of variance program far exceeds the critical F-ratio of 4.38 at the $\alpha = .01$ level of significance. There is a significant statistical difference between the specific gravity values determined by the four test procedures. The BIMED computer output is contained in Appendix G under the problem code SGKAOL.

The specific gravity values determined by the bottle pycnometer method were dropped from the analysis of variance computation and for a null hypothesis it was assumed that there was no significant statistical difference between the specific gravity values determined by the three operating modes of the gas pycnometer. The observed F-ratio computed under these circumstances was 24.42. The critical F-ratio was 5.49 and the null hypothesis was rejected at the $\alpha = .01$ level

TABLE I

Results of specific gravity determinations of ten samples of kaolinite

| SAMPLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | MEAN | STANDARD DEVI-ATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.767 | 2.803 | 2.797 | 2.814 | 2.767 | 2.711 | 2.824 | 2.807 | 2.800 | 2.837 | 2.793 | 0.0359 |
| B | 2.755 | 2.781 | 2.751 | 2.742 | 2.734 | 2.751 | 2.735 | 2.734 | 2.768 | 2.733 | 2.748 | 0.0175 |
| C | 2.688 | 2.719 | 2.716 | 2.701 | 2.722 | 2.724 | 2.713 | 2.717 | 2.737 | 2.732 | 2.717 | 0.0142 |
| C | 2.58 | 2.60 | 2.59 | 2.59 | 2.59 | 2.58 | 2.59 | 2.57 | 2.59 | 2.59 | 2.587 | 0.0082 |

Specific gravities were determined by:

A) Air comparison pycnometer (air, 1-2 atmospheres)
B) Air comparison pycnometer (helium, 1-2 atmospheres)
C) Air comparison pycnometer (helium, 1-1/2-1 atmospheres)
D) 100 milliliter bottle pycnometer (water)

of significance. The BIMED computer output for this computation is included in Appendix G under the problem code SGKACP.

3. Discussion of Results

Figure 12 is a plot of the above results of the kaolinite specific gravity determinations. As may be seen, the bottle pycnometer values fall well below the gas pycnometer values. The bottle pycnometer determinations were made five at a time using approximately 25 gram samples in 100 milliliter volumetric flasks. Air removal was facilitated by gently boiling for ten minutes under a vacuum and then continued application of the vacuum for three hours after removal of the heat source. A subsequent specific gravity measurement using a 50 gram kaolinite sample in a 500 milliliter flask resulted in a value of 2.63. Air removal for this run was provided by evacuation for 12 hours with continuous agitation applied to the flask for the last hour of evacuation, which makes it appear that longer agitation may result in a higher specific gravity value.

Disregarding the sample 6 value for the gas pycnometer using the air operating mode, the results appear to follow an anticipated pattern. All of the air (1-2) mode values for individual samples and the air mode mean value show the greatest difference from corresponding bottle pycnometer values. The helium (1-1/2-1) mode values are all closest to the bottle pycnometer values, while the helium (1-2) mode values all fall between the other two modes.

The standard deviations of the different methods were also ordered indicating the bottle pycnometer method had the least variation while the air (1-2) gas pycnometer mode is least precise, where precision is measured by the spread between individual determinations or

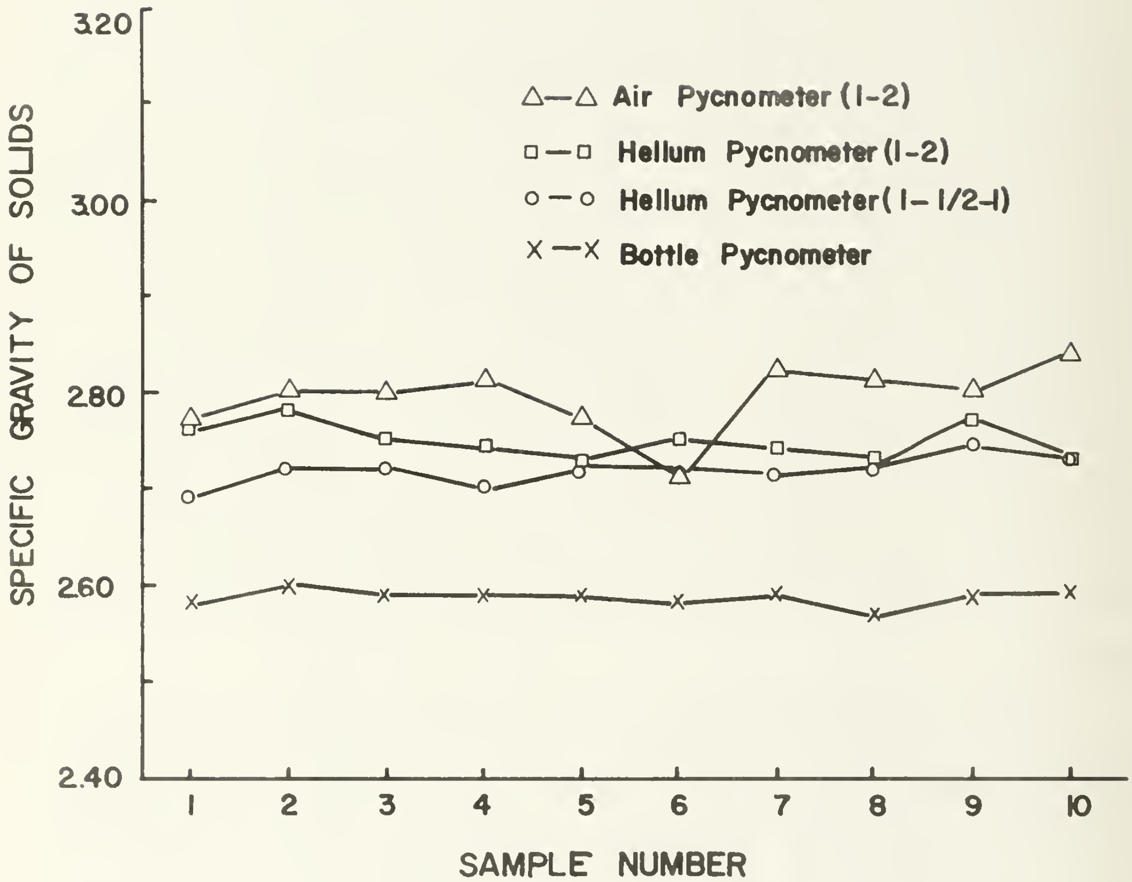


Figure 12. Graph of Kaolinite Results

the standard deviation. Gruner [1937] summarizes the specific gravities of various samples of kaolinite. The nineteen values he listed included other investigators, as well as his own bottle pycnometer and centrifuge determinations and theoretically calculated specific gravities. The values ranged from 2.51 to 2.604, and then fell between 2.580 and 2.600. Though none of the samples were reference standard #4 material, the results substantiate the bottle pycnometer values obtained in this study.

## Specific Gravity Results for Montmorillonite

### 1. General

The clay mineral montmorillonite has the general formula $5Al_2O_3 \cdot 2MgO \cdot 24SiO_2 \cdot 6H_2O$ ($Na_2O$, CaO) and has a three-layer, expanding lattice. It consists of units made up of two silica tetrahedral sheets with a central alumina octahedral sheet. The stacking of the silica-alumina-silica units results in a very weak bond, which permits a lattice expansion when water or other polar molecules enter between the unit layers. Montmorillonite single crystals exhibit a ratio of areal diameter to thickness of from 100:1 to 300:1.

### 2. Results

The results of the specific gravity determinations on the ten montmorillonite fractions are shown in Table II.

The observed F-ratio for this test was 44.96 as computed by the BIMED program and the critical F-ratio was 4.38. There is a statistically significant difference at the $\alpha = .01$ level of significance between the specific gravities determined by the four test methods. The

TABLE II

Results of specific gravity determinations of ten samples of montmorillonite

| SAMPLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | MEAN | STANDARD DEVI-ATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.881 | 2.902 | 2.913 | 2.906 | 2.925 | 2.934 | 2.926 | 2.924 | 2.901 | 2.931 | 2.915 | 0.0178 |
| B | 2.795 | 2.809 | 2.837 | 2.808 | 2.820 | 2.851 | 2.840 | 2.830 | 2.812 | 2.838 | 2.825 | 0.0172 |
| C | 2.826 | 2.836 | 2.842 | 2.825 | 2.845 | 2.871 | 2.879 | 2.875 | 2.835 | 2.865 | 2.850 | 0.0211 |
| D | 2.72 | 2.72 | 2.72 | 2.74 | 2.74 | 2.81 | 2.81 | 2.82 | 2.82 | 2.81 | 2.771 | 0.0461 |

Specific gravities were determined by:

A) Air comparison pycnometer (air, 1-2 atmospheres)
B) Air comparison pycnometer (helium, 1-2 atmospheres)
C) Air comparison pycnometer (helium, 1-1/2-1 atmospheres)
D) 500 milliliter bottle pycnometer (water)

BIMED computer output for this test is contained in Appendix G under the problem code name SGKAOL.

The analysis of variance was re-run on the gas pycnometer values without the bottle pycnometer values. The observed F-ratio for this case is 63.24 and the critical F-ratio is 5.49. Thus the null hypothesis that there is no statistically significant difference between the gas pycnometer values is rejected at the $\alpha = .01$ level of significance. The BIMED computer output for this calculation is included in Appendix G under the problem code name SGMACP.

3. Discussion of Results

Figure 13 graphically illustrates the results of the montmorillonite specific gravity determinations. As may be seen, the bottle pycnometer values fall below those of the air comparison pycnometer except for sample #9. The bottle pycnometer determinations were made five at a time using approximately 25 gram samples in 500 milliliter pycnometer bottles. A conspicuous difference was noted between the first and the last five of the determinations, which may be explained by more complete air removal in the case of the last five tests. For the first five determinations the bottles were evacuated for eight hours with random agitation throughout this period. The last five runs were evacuated for ten to twelve hours and each bottle was hand agitated for at least 30 minutes during the last three hours of the evacuation period. It may be seen that the last five of the bottle pycnometer values compare well with the gas pycnometer values using the helium (1-2 atomspheres) mode.

The air operating mode gas pycnometer values are comparatively high and the furthest removed from the bottle pycnometer results, as was

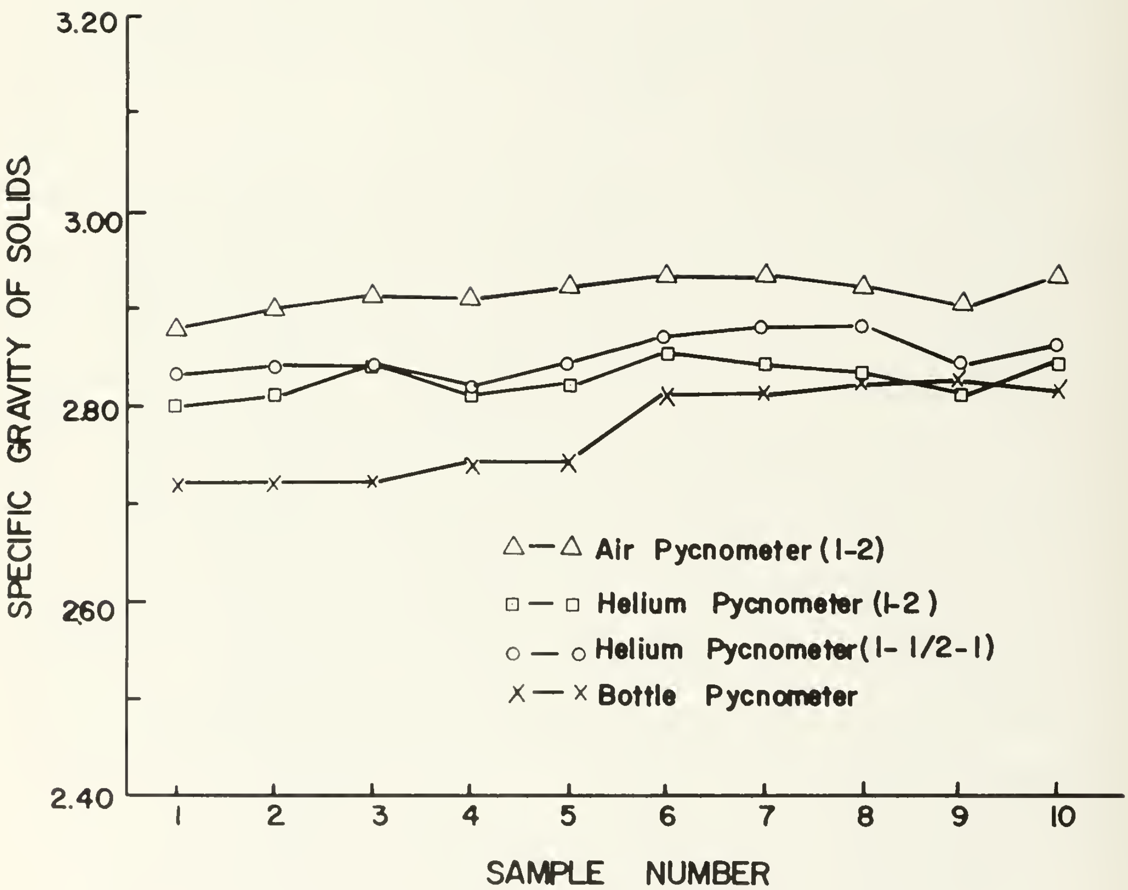


Figure 13. Graph of Montmorillonite Results

the case for the kaolinite tests. The helium (1-1/2-1 atmospheres) mode values are slightly higher than the helium (1-2 atmospheres) values. This last observation for the montmorillonite samples is in opposition to the finding for the same two modes with kaolinite.

The standard deviations for the gas pycnometer determinations range from 0.0172 to 0.0211, indicating the precision for the three modes is about the same. This is different from the standard deviations for kaolinite, where the precision varied with the operating mode. The standard deviation for the bottle pycnometer readings is high as a result of the large difference between the first and last five values.

Various values for the specific gravity of montmorillonite are found in literature. Grim [1953] concludes that the value may range from 2.2 to 2.7 with even higher values possible for materials of high iron content. All of the specific gravity values for this test were higher than any found in literature.

## Specific Gravity Results for Quartz

### 1. General

Silica exists in a number of different crystalline forms with quartz being the most common. Frondel [1962] indicates the specific gravity of quartz at 760 millimeters of mercury at 18 to 20°C as approximately 2.6510 referred to distilled water at 4°C.

### 2. Results

The results of the specific gravity determinations on twelve powdered quartz samples are shown in Table III. An observed F-ratio of 1.22 was computed by the BIMED analysis of variance program. The critical F-ratio for this test was 2.82 at the $\alpha = .05$ level of significance. The null hypothesis was therefore accepted for the

TABLE III

Results of specific gravity determinations of twelve samples of quartz

| SAMPLE NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | MEAN | STAND-ARD DEVI-ATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 2.646 | 2.650 | 2.659 | 2.652 | 2.651 | 2.658 | 2.652 | 2.642 | 2.649 | 2.643 | 2.651 | 2.661 | 2.6508 | 0.0067 |
| B | 2.638 | 2.658 | 2.640 | 2.652 | 2.659 | 2.656 | 2.656 | 2.661 | 2.652 | 2.648 | 2.656 | 2.657 | 2.6542 | 0.0079 |
| C | 2.670 | 2.673 | 2.676 | 2.672 | 2.664 | 2.656 | 2.681 | 2.673 | 2.671 | 2.679 | 2.675 | 2.677 | 2.6725 | 0.0075 |
| D | 2.84 | 2.65 | 2.66 | 2.64 | 2.65 | 2.67 | 2.60 | 2.64 | 2.66 | 2.63 | 2.65 | 2.65 | 2.6617 | 0.0589 |

Specific gravities were determined by:

A) Air comparison pycnometer (air, 1-2 atmospheres)
B) Air comparison pycnometer (helium, 1-2 atmospheres)
C) Air comparison pycnometer (helium, 1-1/2-1 atmospheres)
D) 100 milliliter bottle pycnometer (water)

quartz test. There is no significant statistical difference between the specific gravities obtained by the four determination techniques. The BIMED computer output for this test is contained in Appendix D under the problem code SGQUTZ.

3. Discussion of Results

Figure 14 is a plot of the results of the quartz specific gravity determinations. Two obviously erroneous determinations are apparent for the bottle pycnometer method, and these contribute to the large standard deviation for this method as compared to the gas pycnometer modes. The bottle pycnometer values were determined three-at-a-time using approximately 25 gram samples in 100 milliliter flasks. Air removal was facilitated by boiling for 10 minutes under vacuum with continuous agitation followed by continued evacuation for 8 to 10 hours with random agitation.

The gas pycnometer values for the helium (1-1/2-1 atmospheres) mode are all higher than the rest of the values, although the standard deviation for this mode compares favorably with the variability of the other two modes. It is believed that the zero-measurement check for this mode is not dependable, and may result in an erroneous tare number. The helium (1-2 atmospheres) mode mean specific gravity is very close to the known specific gravity of quartz, and its standard deviation is also small. The closest mean value and the smallest standard deviation for the quartz samples were for the air (1-2 atmospheres) mode.

Specific Gravity Results for Sediment Core

1. General

The sediment core analyzed was collected off the California coast on 5 February 1970 at latitude 36°36' North and longitude 123°56' West

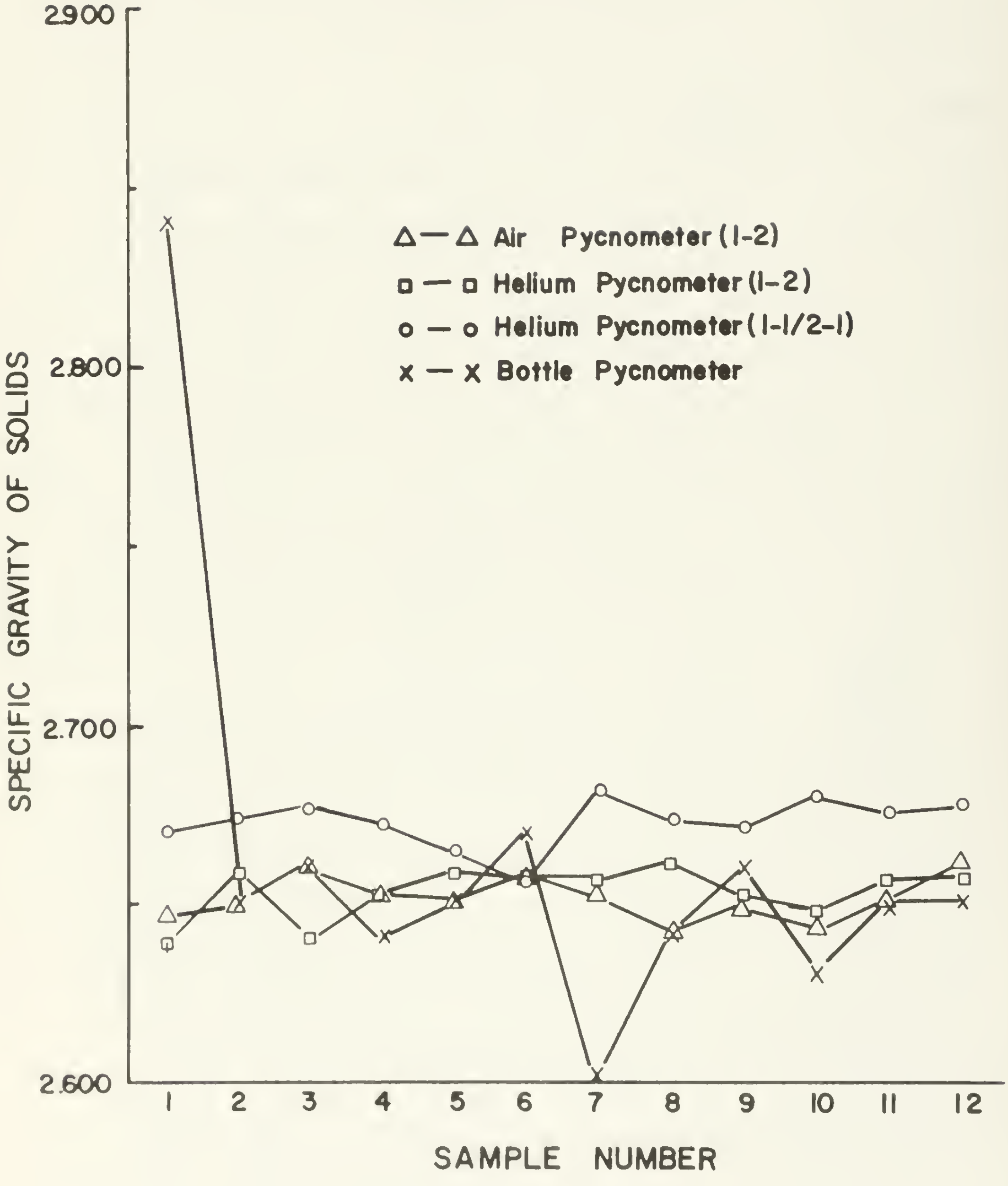


Figure 14. Graph of Quartz Results

in a water depth of 4200 meters. The core was approximately 50 inches in length, and alternate four inch intervals of the core were subjected to testing.

2. Results

The results of the specific gravity determinations on the eight sample core intervals are shown in Table IV. A statistical analysis is not applicable to these results.

3. Discussion of Results

Figure 15 is a graph of the results of the sample core specific gravity determinations. It is apparent that the bottle pycnometer values are generally lower than the gas pycnometer values. The helium (1-2 atmospheres) mode values are, for all intervals, closest to the bottle pycnometer readings. The air (1-2 atmospheres) mode values were intermediate to the helium mode values for the first three intervals, but the remainder of the readings were considerably higher than the helium values. Perhaps an incorrect tare was applied to the last four determinations for the air mode.

Both the bottle pycnometer and gas pycnometer methods indicate a discontinuity, or low specific gravity value, in the middle of the core. The three gas pycnometer modes indicated the low value at the 19-22 inch interval, while the bottle pycnometer method indicated a low specific gravity at the 25-28 inch interval.

TABLE IV

Results of specific gravity determination of eight alternate intervals of a 50 inch core sample

| CORE INTERVAL | 1-4 | 7-10 | 13-16 | 19-22 | 25-28 | 31-34 | 37-40 | 43-46 |
|---|---|---|---|---|---|---|---|---|
| A | 2.922 | 2.989 | 2.959 | 2.886 | 3.011 | 3.074 | 3.138 | 2.976 |
| B | 2.908 | 2.943 | 2.927 | 2.819 | 2.880 | 2.899 | 2.929 | 2.874 |
| C | 2.923 | 3.018 | 2.974 | 2.836 | 2.876 | 2.931 | 2.965 | 2.868 |
| D | 2.69 | 2.73 | 2.74 | 2.74 | 2.60 | 2.74 | 2.75 | 2.73 |

Specific gravities were determined by:

A) Air comparison pycnometer (air, 1-2 atmospheres)
B) Air comparison pycnometer (helium, 1-2 atmospheres)
C) Air comparison pycnometer (helium 1-1/2-1 atmospheres)
D) 500 milliliter bottle pycnometer (water)

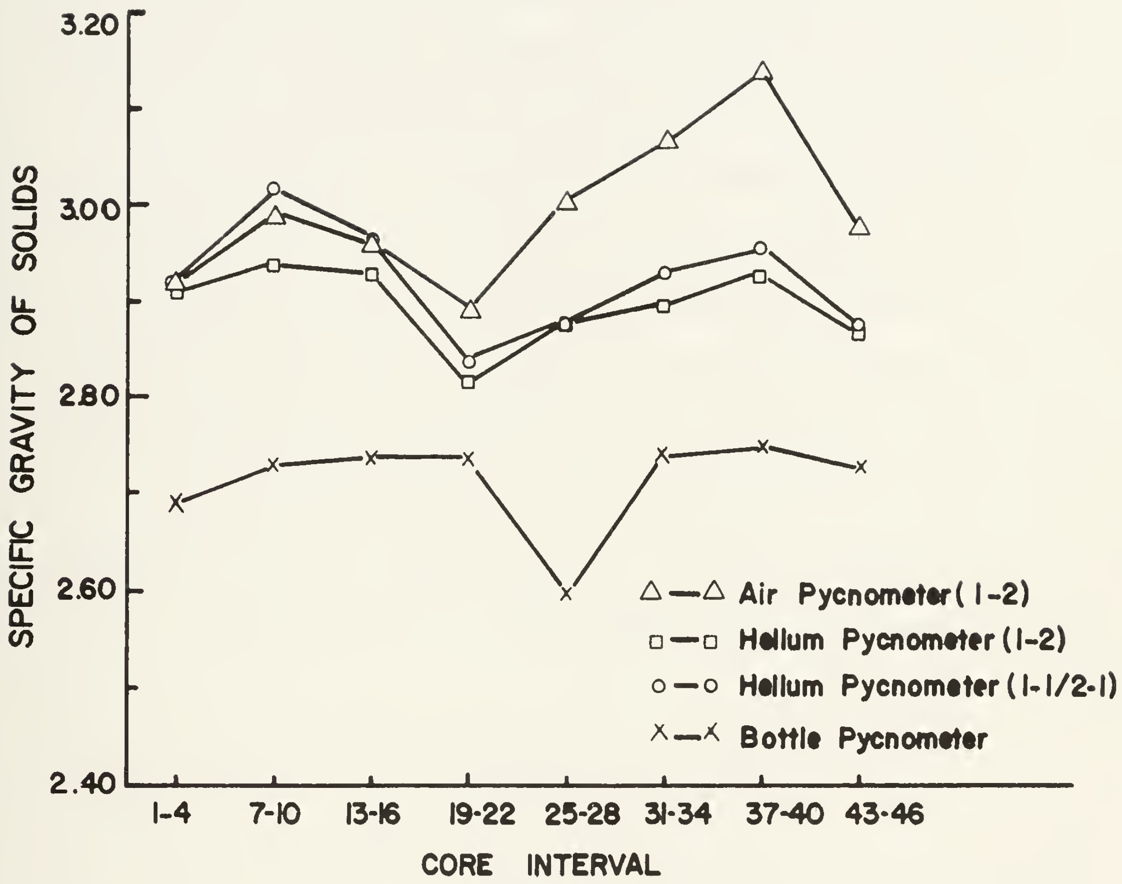


Figure 15. Graph of Sample Core Results

## V. CONCLUSIONS AND RECOMMENDATIONS

The most apparent result of this work is that gas pycnometer specific gravity values were consistently higher than values determined by means of a bottle pycnometer for colloidal clays and sediments. The surface activity of such fine-grained material together with the most probable source of error, leakage around the sample cup gasket, both tend to contribute to abnormally high values for the gas pycnometer. The most frequent error for the bottle pycnometer method results from inadequate de-airing of the suspended sediment, and this contributes to a low specific gravity value for this method. Since a material exhibiting colloidal behavior and having a well-established specific gravity is not available for testing, it is impossible to ascertain which method gives the more correct specific gravity. It does appear that the true value is probably intermediate between the bottle and gas pycnometer determinations.

It is suggested that further investigation be made of the characteristics and behavior of the air comparison pycnometer. In the present investigation only one system evacuation and helium purge cycle was performed for each volume determined. The slow drift of the differential pressure indicator toward a smaller volume, a sign of surface activity, although much reduced after one evacuation and purge cycle was still present. Since helium absorption is supposedly almost non-existent at normal room temperatures [Gregg, 1961], it is suspected that not all of the air was removed from the system. Therefore repeated cycling of the evacuation and helium purge might remove more air and measurably reduce the surface activity resulting in a lower, more correct specific gravity. Waterman and Wolfs [1957] have found that the helium gas used should be free of foreign gases that might be absorbed to the sample, and recommended a purification procedure which requires passing the gas over activated charcoal at about -190°C. The helium used in the present study was standard Navy Grade A (medical grade) helium that was water pumped. It is possible that water vapor was still present in this gas.

It proved very difficult to obtain consistent zero cup readings for the helium (1-1/2-1 atmospheres) mode. Consistent tare readings were obtained using the large calibration ball, these being the difference between the volume as determined for the calibration ball and its actual volume. These tare values were used for this mode. For the other two modes a tare value was established from three successive zero cup readings within $\pm$ 0.01 cubic centimeters. The average value of these three readings was applied to a calibration ball determination to ensure that the tare value allowed the calibration ball volume to fall within $\pm$ 0.015 cubic centimeters of its known volume. It must therefore be concluded that the (1-1/2-1 atmospheres) helium mode is subject to inconsistencies.

It is recommended that when the bottle pycnometer method is used the air removal procedure include evacuation with the sample bottle mounted on a vibrating table.

It is further suggested that some attempt be made to find a way to neutralize the surface activity of colloidal materials prior to the volume determination by the gas pycnometer. A solution may be to apply a tare to the gas pycnometer readings to account for the effects of surface activity, or perhaps to treat the sample chemically or electrically to negate the tendency to absorb constituents of the gaseous comparison medium.

# APPENDIX A

## COPIES OF REVIEW CORRESPONDENCE

The letters in this appendix are examples of typical correspondence addressed to academic institutions, commercial firms, laboratories, and individuals working in the field relative to specific gravity measurement practices.

NAVAL POSTGRADUATE SCHOOL
DEPARTMENT OF OCEANOGRAPHY
MONTEREY. CALIFORNIA 93940

Dear Sir:

At the present time the Naval Postgraduate School in conjunction with the Naval Facilities Engineering Command is undertaking a research program to improve techniques for determining the specific gravity of marine sediments. In particular, we are interested in ascertaining the most suitable and reliable methods of determining the specific gravity of fine particulate matter, and the advantages and disadvantages of the various methods in use. The use of the air comparison pycnometer for this purpose is also of special interest.

Attached is a short questionaire, and we ask that you complete the form as applicable for an input into this project. An addressed envelope is enclosed for the return of the completed form.

It is our intent to improve on the present methods used for specific gravity determination in relation to the analysis of the physical properties of marine sediments, and your assistance would be greatly appreciated. If you have material applicable to this field of research that is in excess of that asked for on the questionaire, would you please forward it to the following address:

SUPERINTENDENT
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940
(CODE 35 - OPG 8)

Very truly yours,

J. C. Henderson

Name
------------------------------------------
Address
---------------------------------------

---------------------------------------

Is your facility/ company involved in the determination of the specific gravity of marine sediments/ fine particulate matter/ clays.

YES ------ NO ------

What method do you employ to determine specific gravity (displacement of fluid/ weight and volume measurements/ etc.).

What device do you employ to determine specific gravity/ weight/ volume of your sample.

What accuracy do you consider you achieve with the method and equipment you employ.

Do you know any other person(s) or institution(s) involved in the specific gravity determination of marine sediments/ fine grained particles/ clays.

Could more information concerning this project be obtained by personal contact through further correspondence or a visit to your facility.

YES ------ NO ------

Would you like to be advised of the results of this project.

YES ------ NO ------

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

DEPARTMENT OF OCEANOGRAPHY

Dear Sir:

At the present time the Naval Postgraduate School in conjunction with the Naval Facilities Engineering Command is undertaking a research program to improve techniques for determining the specific gravity of marine sediments. In particular, we are interested in ascertaining the most suitable and reliable methods of determining the specific gravity of fine particulate matter, and the advantages and disadvantages of the various methods in use. The use of the air comparison pycnometer for this purpose is also of special interest.

We are interested in obtaining information concerning the capabilities, cost, and accuracy of any equipment your firm may build or distribute that could be used for specific gravity measurements. A list of users of your equipment in California and surrounding states would also be most helpful.

It is our intent to improve on the present methods used for specific gravity determinations in relation to the analysis of the physical properties of marine sediments, and your assistance would be greatly appreciated. If you have material in the form of technical reports applicable to this field of research, would you please forward them along with the equipment information to the following address:

SUPERINTENDENT
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940
(CODE 35 - OPG 8)

Very truly yours,

J. C. Henderson

# APPENDIX B

## SUMMARY OF REVIEW COMMENTS

This appendix contains a listing of academic institutions, commercial firms, laboratories, and individuals who responded to the review correspondence, together with notes of particular interest relative to specific gravity determinations. The citing of an academic institution indicates a response from one or more of the departments of chemistry, geology, civil engineering, or oceanography of that institution.

ACADEMIC INSTITUTIONS

| Institution | Comment |
|---|---|
| University of Alabama | |
| University of Alberta | Department of Oceanography, bottle pycnometer for marine sediments, accuracy of ± 0.01. |
| University of Arizona | Department of Geology, Berman Density Balance for fine mineral particles, accuracy of ± 0.01. |
| University of Arkansas | |
| Baylor University | |
| Brigham Young University | |
| University of British Columbia | |
| Brown University | |
| University of California (Davis) | |
| University of California (Los Angeles) | Department of Civil Engineering, bottle pycnometer for soils, accuracy of ± 0.01. |
| Catholic University | Department of Oceanography, bottle pycnometer for sediments, accuracy of ± 0.01. |
| University of Colorado | Department of Civil Engineering, bottle pycnometer for soils, accuracy of ± 0.01. |
| Cornell University | |
| University of Delaware | |
| Duke University | Department of Civil Engineering, bottle pycnometer for soils, accuracy of ± 0.01. |
| Florida Atlantic University | |

| Institution | Comment |
|---|---|
| University of Florida | |
| Florida Institute of Technology | |
| Florida State University | |
| Fordham University | |
| Georgia Institute of Technology | Department of Civil Engineering, bottle pycnometer for clays, accuracy of $\pm$ 1% or 2%. |
| University of Georgia | Oceanography graduate student, plastic vial of known volume plus weight determination for wet density of marsh muds, accuracy of $\pm$ 5%. |
| Harvard University | |
| University of Hawaii | Department of Oceanography, precision glass tube for volume plus weight for density of sediments. |
| University of Houston | |
| Humbolt State College | |
| University of Illinois | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.01. |
| Chicago State College | |
| Indiana University | |
| Iowa State College | Department of Civil Engineering, bottle pycnometer for soils, accuracy to fourth decimal place. |
| University of Iowa | |
| John Hopkins University | |
| University of Kansas | Department of Civil Engineering, bottle pycnometer for soils and clays, accuracy of $\pm$ 10%. |

| Institution | Comment |
|---|---|
| Kansas State College | |
| University of Kentucky | Department of Civil Engineering, bottle pycnometer for soils and clays. |
| Long Island University | |
| Louisiana State University | |
| University of Maine | |
| University of Maryland | |
| Massachusetts Institute of Technology | Department of Civil Engineering, bottle pycnometer for clays, accuracy of $\pm$ 0.005. |
| University of Massachusetts | |
| McGill University | |
| University of Miami | |
| Michigan State University | |
| University of Michigan | Department of Civil Engineering, bottle pycnometer for soils and clays, accuracy of $\pm$ 0.01. |
| University of Minnesota | Department of Civil Engineering, bottle pycnometer for clays, accuracy of $\pm$ 0.01. |
| University of Missouri | |
| University of New Hamshire | Department of Oceanography, air comparison pycnometer for sediments, accuracy of $\pm$ 10%. |
| University of North Carolina | |
| New York University | |
| City University of New York | |

| Institution | Comment |
|---|---|
| University of Notre Dame | Department of Geology, Berman Balance for small mineral samples. Department of Civil Engineering, bottle pycnometer for fine grain soils and clays, accuracy of $\pm$ 0.01. |
| Ohio State University | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.5. |
| Old Dominion College | |
| Oregon State University | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.01. |
| Pennsylvania State University | Department of Civil Engineering, bottle pycnometer for clays, ASTM tolerance $\pm$ 0.002. |
| University of Pennsylvania | |
| University of Pittsburg | Department of Civil Engineering, bottle pycnometer for soils and clays |
| Princeton University | |
| Purdue University | Department of Civil Engineering, bottle pycnometer for marine sediments and clays, accuracy of $\pm$ 0.04. |
| Queen's University | |
| Rensselaer Polytechnic Institute | Department of Geology, bottle pycnometer for soil sediments. Department of Civil Engineering, bottle pycnometer for soils and clays, accuracy of 1 in 300. |
| University of Rhode Island | |
| Rugters University | |
| San Diego State College | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.01 after evacuation for 24 to 48 hours on vibrating table. |
| San Francisco State College | |

| Institution | Comment |
| --- | --- |
| San Jose State College | Department of Geology, bottle pycnometer for minerals, accuracy within 1%. |
| University of Southern California | |
| Southern Methodist University | |
| University of Southern Florida | |
| Stanford University | |
| Syracuse University | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.1. |
| University of Tennessee | Department of Geology, centrifugation in constant density gradient liquid for minerals, density accuracy to $\pm$ 0.005 gm/cc. |
| University of Texas | |
| Agricultural and Mechanical College of Texas | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.02. |
| University of Utah | Department of Civil Engineering, bottle pycnometer for soils. |
| Vanderbilt University | |
| University of Virginia | Department of Civil Engineering, bottle pycnometer for soils, accuracy of $\pm$ 0.01. |
| University of Washington | |
| University of Wisconsin | Department of Civil Engineering, air comparison pycnometer for soils, accuracy $\pm$ 0.5%. |
| Yale University | Department of Geology, differential gravity tube for minerals, accuracy of $\pm$ .001. |

LABORATORIES AND INDIVIDUALS

| Laboratory or Individual | Comment |
|---|---|
| Phillip P. Brown<br>Soil Mechanics Consultant<br>Naval Facilities<br>Engineering Command | |
| Michael Duke<br>U. S. Geological Survey | Bottle pycnometer to determine specific gravity of fine particulate matter to better than ± 5%. |
| Dr. I. Robert Ehrlich<br>Davidson Laboratory | Various methods to determine in-situ density of submerged soil sample. |
| Dr. Richard W. Faas<br>Professor of Geology<br>Lafayette College | |
| Dr. Chester Francis<br>Health Physics Division<br>Oak Ridge National Laboratory | Isopycnic zonal centrifugation to determine density of clays to ± 0.05 g/cc depending on purity of sample. |
| Mr. W. H. Glezen<br>Gulf Research and<br>Development Company | Air comparison pycnometer with helium to determine specific gravity of shales to ± 0.5% (i.e., 2.70 ± 0.01). |
| Dr. Thomas Gold<br>Department of Astronomy<br>Cornell University | |
| Dr. M. Grant Gross<br>Marine Sciences Institute<br>State University of New York | Air comparison pycnometer to determine specific gravity of marine sediments. Accuracy never properly evaluated. |
| Dr. J. J. Grossman<br>Missiles and Space Systems<br>Douglas Aircraft | |
| Dr. George Keller<br>Atlantic Oceanographic<br>Laboratory<br>ESSA | Bottle pycnometer to determine specific gravity of marine sediments to ± .005 accuracy |

| Laboratory of Individual | Comment |
|---|---|
| L. B. Macurdy<br>Mettler Balance Company | Hydrostatic weighing techniques. Accuracy varies with size of sample. |
| Dr. James Rucker<br>Sediment Laboratory<br>Naval Oceanographic Office | Bottle pycnometer to determine specific gravity of marine sediments. Repeatability to 0.01 to 0.02 specific gravity value. |
| Dick Seiter<br>Bechtel Corporation | Bottle pycnometer to determine specific gravity to ± 0.2%. |
| Leonard Shapiro<br>U. S. Geological Survey | Sink-float technique to determine powder density of rocks. Sample size is approximately 50 mg. Accuracy ± 0.04 gm/cc. |
| D. R. Stephens<br>Lawrence Radiation Laboratory | Fabricates sample into known geometry and weighs it. Accuracy of density determination is ± 0.2%. |
| Howard Sutter<br>Baroid Division<br>National Lead Company | LeChatelier flasks to determine specific gravity to less than 1.0%. |
| Director, Geology Section<br>U. S. Bureau of Mines | The bottle pycnometer used with accuracy to three decimal places. Samples of fine particulate matter are tested in a 500 ml. flask with de-airing by vacuum. The flask is placed in a water bath shaker maintained around 20°C. The flask is weighed on a balance readable to 0.1 gm. Air comparison pycnometer also used with helium purge with accuracy of ±.015. |
| Director<br>Marine Geology Division<br>Shell Research | Primarily interested in bulk density rather than grain density. |
| Director<br>Soil Mechanics Division<br>Waterway Experiment Station | Bottle pycnometer method used. Duplicate tests are conducted and considered valid if results agree within ± 0.01. |

COMMERCIAL FIRMS

| Name of Firm | Comment |
|---|---|
| Wm. Ainsworth, Inc. | |
| American Instrument Co., Inc. | |
| Bailey Meter Company | |
| The Bissett-Berman Corporation | |
| Brinkman Instruments, Inc. | Manufactures a number of balances which may be modified for specific gravity determination. |
| R. P. Cargille Labs, Inc. | |
| Cintra International Company | |
| Cox Instrument | |
| Curtin Scientific Company | |
| Eberback Corporation | Manufactures Kraus Jolly Balance which measures specific gravity of solids - sample weights up to 300 grams may be used. |
| Engineered Materials | Distributes specific gravity testing set. Can be used for specific gravity determination of single mineral. Uses heavy liquids which are toxic. Generally used for heavy mineral separation. |
| Enraf-Nonius, Inc. | |
| Federal Scientific Company | Manufactures Berman density balance. Range of sample size 15 to 25 mg. |
| Fisher Scientific Company | |
| The Foxboro Company | |
| Gardener Laboratory, Inc. | |
| Geoliquids Division National Biochem Company | Manufactures density gradient tube and calibrated liquids. |

| Name of Firm | Comment |
|---|---|
| Gilford Instruments Lab., Inc. | |
| Gow-Mac Instrument Company | |
| Hallikainen Instruments | |
| The Heusser Instrument Company (Utah) | Manufactures model SG-203 balance specifically for specific gravity determination. Weighs up to 12 gram sample in air and in desired fluid. Simple calculation is required for specific gravity. Reading range: 0.62 g/ml -1.85 gm/ml to a 0.001 precision. |
| Heusser Instrument Company West Coast Division | |
| International Light, Inc. | |
| Kay-Ray, Inc. | |
| Kimble Products | |
| Lab Glass, Inc. | |
| David W. Mann Company | |
| Microscale, Ltd. | |
| Nuclear-Chicago | |
| Numec Instruments and Controls Corporation | |
| The Ohmart Corporation | Manufactures Model 310 and 311 balances which can be modified to make specific gravity determinations. |
| Pope Scientific, Inc. | |
| Princo Instruments, Inc. | |
| Prolabo | |
| Roller-Smith | Manufactures Berman density balance. |
| Ruska Instrument Corporation | |

| Name of Firm | Comment |
|---|---|
| Schoeffel Instrument Corp. | |
| Scientific Glass Apparatus Company, Inc. | |
| Sherwood Medical Industries, Inc. | |
| Shimadzu Seisakusho, Ltd. | |
| Techne Incorporated | Manufactures TECAM density gradient column. |
| Technical Operations, Inc. | |
| Testing Machine, Inc. | |
| Texas Instruments, Inc. | Manufactures precision pressure equipment which may be used as part of a system to measure volume of an unknown. |
| Industrial Products Div. Thermometer Corporation of America | |
| Arthur H. Thomas Company | TECAM density gradient column for measuring density of small solid samples with precision approaching $\pm$ 0.0002 g/ml. |
| The Torsion Balance Company | |
| Henry Troemner, Inc. | Manufactures model S-100 balance specifically for specific gravity determination. |
| Cahn Division Ventron Instruments Corp. | Manufactures Cahn density system which measures density of 1.5 mg sample to accuracy of six decimal places. |
| Voland Corporation | |
| West-Glass Corporation | |

## APPENDIX C

### DERIVATION OF AN EQUATION RELATING SPECIFIC GRAVITY, BULK WET DENSITY, AND WATER CONTENT

Water content is defined as the weight of water in a sample divided by the weight of solids in the sample.

$$WC = \frac{W_w}{W_s} \tag{1}$$

In that the weight of a material is equal to the volume of the material times its density, equation (1) becomes:

$$WC = \frac{V_w \times D_w}{V_s \times D_s} \tag{2}$$

If the numerator and denominator of (2) are divided by the density of water at $4^{o}C$, equation (2) becomes

$$WC = \frac{V_w \times \frac{D_w}{D_4}}{V_s \times \frac{D_s}{D_4}} \tag{3}$$

$D_w/D_4$ is the specific gravity of water and can be assumed equal to one for this derivation. $D_s/D_4$ is the specific gravity of solids. Equation (3) then becomes

$$WC = \frac{V_w}{V_s \times G_s} \tag{4}$$

Bulk wet density is defined as the weight of a wet sample divided by its volume:

$$BWD = \frac{W_t}{V_t} \; . \tag{5}$$

Ignoring the dissolved salts, the total weight of water is the weight of solids plus the weight of water, and the total volume is the volume of solids plus the volume of water. Equation (5) becomes:

$$BWD = \frac{W_w + W_s}{V_w + V_s} \; . \tag{6}$$

Again using the definition that weight equals volume times density, assuming the specific gravity of water is one, and dividing the numerator and denominator of (6) by the density of distilled water at $4^oC$, equation (6) becomes:

$$BWD = \frac{V_w + V_s \times G_s}{\frac{V_w + V_s}{D_4}} \tag{7}$$

The density of distilled water at $4^oC$ is one gram per cubic centimeter, and equation (7) is simplified to:

$$BWD = \frac{V_w + V_s \times G_s}{V_w + V_s} \tag{8}$$

Dividing the numerator and denominator of equation (8) by $V_w$ results in:

$$BWD = \frac{1 + G_s \times \frac{V_s}{V_w}}{1 + \frac{V_s}{V_w}} \tag{9}$$

Equation (4) may be directly substituted into equation (9) to obtain:

$$BWD = \frac{1 + \frac{1}{WC}}{1 + \frac{V_s}{V_w}} \tag{10}$$

Equation (4) may be rearranged in the form:

$$\frac{V_s}{V_w} = \frac{1}{WC \times G_s} \tag{11}$$

and equation (11) may be substituted into equation (10) to form:

$$BWD = \frac{1 + \frac{1}{WC}}{1 + \frac{1}{WC \times G_s}} \tag{12}$$

Equation (12) may be solved for $G_s$ to obtain:

$$G_s = \frac{BWD}{1 + WC - (BWD \times WC)} \; . \tag{13}$$

Symbols used in this derivation are:

WC = water content (expressed as a percentage)

$W_w$ = weight of water (grams)

$W_s$ = weight of solids (grams)

$D_w$ = density of water (grams per cubic centimeter)

$D_s$ = density of solids (grams per cubic centimeter)

$D_4$ = density of distilled water at $4^{o}$C (grams per cubic centimeter)

$G_s$ = specific gravity of solids

$V_w$ = volume of water (cubic centimeters)

$V_s$ = volume of solids (cubic centimeters)

BWD = bulk wet density (grams per cubic centimeter)

$W_t$ = total weight of solids and water (grams)

$V_t$ = total volume of solids and water (grams).

# APPENDIX D

## COMPUTER PROGRAM

This appendix contains a computer program for the calculation of specific gravity using bulk wet density and water content. The program also compares the computed value with the specific gravity by actual determination.

```
C      COMPARISON OF SPECIFIC GRAVITIES BY FORMULA AND DIRECT DETERMINATION

CL1 AND CL2 = CORE LOCATION
CN1 AND CN2 = CORE NUMBER
CI1 AND CI2 = CORE INTERVAL
SGACP = SPECIFIC GRAVITY BY AIR COMPARISON PYCNOMETER
SGCAL = SPECIFIC GRAVITY BY CALCULATION
PMD =  PARTICLE MEDIAN DIAMETER
BWD = BULK WEIGHT DENSITY
WC = WATER CONTENT


    1 READ(5,2)CL1,CL2,CN1,CN2,CI1,CI2,BWD,WC,SGACP,PMD,ILAST
    2 FORMAT(2A4,2A4,2A4,F6.3,2F10.3,F10.4,I1)
      SGCAL=BWD/(1.0+WC-BWD*WC)
      DIFF=SGACP-SGCAL
      WRITE(6,3)CL1,CL2,CN1,CN2,CI1,CI2,BWD,WC,PMD,SGACP,SGCAL,DIFF
    3 FORMAT(1X,2A4,2A4,2A4,2F10.3,F10.4,3F10.3)
      IF(ILAST.EQ.1) STOP
      GO TO 1
      END
```

## APPENDIX E

### COMPUTER OUTPUT FOR NCEL DATA

The computer output for the Naval Civil Engineering Laboratory data is contained in this appendix. Specific gravity values were determined by the computer program in Appendix D and the air comparison pycnometer. Median diameters are in millimeters. A zero reading in the median diameter column indicates that no grain size analysis data was available for that interval.

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-01B | 0-3 | 1.350 | 1.326 | 0.0009 | 2.760 | 2.519 | 0.241 |
| | | 6-9 | 1.336 | 1.356 | 0.0012 | 2.750 | 2.454 | 0.296 |
| | | 12-15 | 1.330 | 1.458 | 0.0010 | 2.748 | 2.563 | 0.185 |
| | | 18-21 | 1.342 | 1.604 | 0.0005 | 2.790 | 2.973 | -0.183 |
| EAST PAC | BS-02B | 0-3 | 1.355 | 1.469 | 0.0009 | 2.856 | 2.832 | 0.024 |
| | | 6-9 | 1.360 | 1.271 | 0.0012 | 2.761 | 2.507 | 0.254 |
| | | 12-15 | 1.334 | 1.467 | 0.0007 | 2.829 | 2.616 | 0.213 |
| | | 18-21 | 1.332 | 1.494 | 0.0005 | 2.918 | 2.643 | 0.275 |
| | | 24-27 | 1.342 | 1.450 | 0.0009 | 2.761 | 2.662 | 0.099 |
| | | 30-33 | 1.353 | 1.348 | 0.0008 | 2.931 | 2.581 | 0.350 |
| EAST PAC | BS-03B | 0-3 | 1.381 | 1.276 | 0.0008 | 3.037 | 2.688 | 0.349 |
| | | 6-9 | 1.347 | 1.315 | 0.0007 | 3.015 | 2.477 | 0.538 |
| | | 12-15 | 1.337 | 1.486 | 0.0007 | 3.046 | 2.678 | 0.368 |
| | | 18-21 | 1.342 | 1.414 | 0.0008 | 3.081 | 2.599 | 0.482 |
| | | 24-27 | 1.371 | 1.424 | 0.0009 | 3.071 | 2.907 | 0.164 |
| EAST PAC | BS-04B | 0-3 | 1.379 | 1.249 | 0.0009 | 2.712 | 2.619 | 0.093 |
| | | 6-9 | 1.360 | 1.485 | 0.0008 | 2.689 | 2.922 | -0.233 |
| | | 12-15 | 1.352 | 1.423 | 0.0007 | 2.692 | 2.709 | -0.017 |
| | | 18-21 | 1.369 | 1.510 | 0.0005 | 2.669 | 3.092 | -0.423 |
| | | 24-27 | 1.407 | 1.271 | 0.0006 | 2.684 | 2.915 | -0.231 |
| | | 30-33 | 1.343 | 1.289 | 0.0008 | 2.686 | 2.407 | 0.279 |
| EAST PAC | BS-05B | 0-3 | 1.201 | 1.486 | 0.0010 | 2.676 | 1.712 | 0.964 |
| | | 6-9 | 1.231 | 1.623 | 0.0018 | 2.620 | 1.969 | 0.651 |
| | | 12-15 | 1.307 | 2.036 | 0.0014 | 2.633 | 3.486 | -0.853 |
| | | 18-21 | 1.309 | 2.088 | 0.0009 | 2.706 | 3.689 | -0.983 |
| | | 24-27 | 1.389 | 1.610 | 0.0010 | 2.655 | 3.717 | -1.062 |
| | | 30-33 | 1.369 | 1.668 | 0.0011 | 2.701 | 3.560 | -0.859 |
| | | 36-39 | 1.414 | 1.481 | 0.0016 | 2.620 | 3.655 | -1.035 |
| | | 42-45 | 1.410 | 1.437 | 0.0014 | 2.746 | 3.432 | -0.686 |
| | | 48-51 | 1.360 | 1.411 | 0.0020 | 2.688 | 2.764 | -0.076 |
| | | 54-57 | 1.351 | 1.570 | 0.0012 | 2.703 | 3.009 | -0.306 |
| | | 60-63 | 1.371 | 1.645 | 0.0009 | 2.701 | 3.518 | -0.817 |
| | | 66-69 | 1.386 | 1.505 | 0.0014 | 2.713 | 3.307 | -0.594 |
| | | 72-75 | 1.497 | 0.596 | 0.0060 | 2.685 | 2.127 | 0.558 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-06B | 0-3 | 1.361 | 1.494 | 0.0012 | 2.799 | 2.954 | -0.155 |
| | | 6-9 | 1.445 | 1.367 | 0.0014 | 2.726 | 3.689 | -0.963 |
| | | 12-15 | 1.419 | 1.342 | 0.0015 | 2.692 | 3.242 | -0.550 |
| | | 18-21 | 1.975 | 0.317 | 0.0380 | 2.714 | 2.858 | -0.144 |
| | | 24-27 | 1.487 | 1.120 | 0.0019 | 2.773 | 3.271 | -0.498 |
| EAST PAC | BS-07B | 0-3 | 1.276 | 1.285 | 0.0014 | 2.839 | 1.977 | 0.862 |
| | | 6-9 | 1.287 | 1.181 | 0.0013 | 2.747 | 1.947 | 0.800 |
| | | 12-15 | 1.370 | 1.265 | 0.0015 | 2.742 | 2.575 | 0.167 |
| | | 18-21 | 1.235 | 1.330 | 0.0018 | 2.701 | 1.796 | 0.905 |
| | | 24-27 | 1.247 | 1.117 | 0.0023 | 2.695 | 1.722 | 0.973 |
| | | 30-33 | 1.316 | 1.135 | 0.0030 | 2.693 | 2.052 | 0.641 |
| | | 36-39 | 1.366 | 1.114 | 0.0062 | 2.723 | 2.306 | 0.417 |
| | | 42-45 | 1.787 | 0.486 | 0.0250 | 2.718 | 2.894 | -0.176 |
| | | 48-51 | 1.477 | 1.175 | 0.0016 | 2.823 | 3.360 | -0.537 |
| | | 54-57 | 1.454 | 1.298 | 0.0013 | 2.847 | 3.540 | -0.693 |
| | | 60-63 | 1.445 | 1.223 | 0.0012 | 2.664 | 3.170 | -0.506 |
| | | 66-69 | 1.441 | 1.445 | 0.0013 | 2.705 | 3.972 | -1.267 |
| | | 72-75 | 1.438 | 1.328 | 0.0017 | 2.734 | 3.437 | -0.703 |
| | | 78-81 | 1.564 | 0.988 | 0.0026 | 2.686 | 3.532 | -0.846 |
| | | 84-87 | 1.565 | 0.927 | 0.0026 | 2.759 | 3.286 | -0.527 |
| EAST PAC | BS-08B | 0-3 | 1.241 | 1.236 | 0.0016 | 2.806 | 1.767 | 1.039 |
| | | 6-9 | 1.316 | 1.210 | 0.0017 | 2.839 | 2.131 | 0.708 |
| | | 12-15 | 1.393 | 1.303 | 0.0023 | 2.784 | 2.855 | -0.071 |
| | | 18-21 | 1.357 | 1.245 | 0.0032 | 2.720 | 2.443 | 0.277 |
| | | 24-27 | 1.407 | 1.224 | 0.0041 | 2.764 | 2.804 | -0.040 |
| | | 30-33 | 1.465 | 1.256 | 0.0068 | 2.721 | 3.522 | -0.801 |
| | | 36-39 | 1.516 | 1.120 | 0.0014 | 2.714 | 3.592 | -0.878 |
| | | 42-45 | 1.464 | 1.291 | 0.0040 | 2.742 | 3.651 | -0.909 |
| | | 48-51 | 1.486 | 1.305 | 0.0013 | 2.779 | 4.063 | -1.284 |
| | | 54-57 | 1.443 | 1.326 | 0.0012 | 2.783 | 3.497 | -0.714 |
| | | 60-63 | 1.451 | 1.385 | 0.0014 | 2.719 | 3.866 | -1.147 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-09B | 0-3 | 1.389 | 1.446 | 0.0015 | 2.737 | 3.175 | -0.438 |
| | | 6-9 | 1.431 | 1.368 | 0.0009 | 2.719 | 3.487 | -0.768 |
| | | 12-15 | 1.446 | 1.364 | 0.0012 | 2.761 | 3.692 | -0.931 |
| | | 18-21 | 1.436 | 1.368 | 0.0013 | 2.731 | 3.558 | -0.827 |
| | | 24-27 | 1.418 | 1.450 | 0.0012 | 2.764 | 3.600 | -0.836 |
| | | 30-33 | 1.487 | 1.104 | 0.0011 | 2.717 | 3.216 | -0.499 |
| | | 36-39 | 1.476 | 1.178 | 0.0011 | 2.705 | 3.360 | -0.655 |
| | | 42-45 | 1.579 | 1.040 | 0.0015 | 2.718 | 3.969 | -1.251 |
| | | 48-51 | 1.467 | 1.144 | 0.0012 | 2.692 | 3.150 | -0.458 |
| | | 54-57 | 1.514 | 1.195 | 0.0013 | 2.717 | 3.925 | -1.208 |
| | | 60-63 | 1.479 | 1.184 | 0.0013 | 2.727 | 3.417 | -0.690 |
| EAST PAC | BS-12B | 0-3 | 1.340 | 1.689 | 0.0011 | 2.754 | 3.147 | -0.393 |
| | | 6-9 | 1.456 | 1.212 | 0.0034 | 2.684 | 3.255 | -0.571 |
| | | 12-15 | 1.460 | 1.359 | 0.0023 | 2.694 | 3.895 | -1.201 |
| | | 18-21 | 1.616 | 0.792 | 0.0150 | 2.659 | 3.155 | -0.496 |
| EAST PAC | BS-13B | 0-3 | 1.250 | 1.820 | 0.0010 | 2.843 | 2.294 | 0.549 |
| | | 6-9 | 1.426 | 1.451 | 0.0013 | 2.774 | 3.734 | -0.960 |
| | | 12-15 | 1.325 | 1.988 | 0.0046 | 2.722 | 3.744 | -1.022 |
| | | 18-21 | 1.488 | 1.296 | 0.0019 | 2.814 | 4.048 | -1.234 |
| EAST PAC | BS-14B | 0-3 | 1.226 | 1.375 | 0.0014 | 2.720 | 1.779 | 0.941 |
| | | 6-9 | 1.350 | 1.306 | 0.0013 | 2.813 | 2.487 | 0.326 |
| | | 12-15 | 1.446 | 1.154 | 0.0019 | 2.754 | 2.979 | -0.226 |
| | | 18-21 | 1.405 | 1.371 | 0.0014 | 2.734 | 3.159 | -0.425 |
| EAST PAC | BS-15B | 0-3 | 1.377 | 1.548 | 0.0012 | 2.662 | 3.307 | -0.645 |
| | | 6-9 | 1.371 | 1.571 | 0.0036 | 2.708 | 3.287 | -0.579 |
| | | 12-15 | 1.501 | 1.123 | 0.0013 | 2.704 | 3.432 | -0.728 |
| | | 18-21 | 1.404 | 1.434 | 0.0011 | 2.707 | 3.338 | -0.631 |
| | | 24-27 | 1.425 | 1.493 | 0.0012 | 2.723 | 3.899 | -1.176 |
| | | 30-33 | 1.356 | 0.901 | 0.0155 | 2.673 | 1.996 | 0.677 |
| | | 36-39 | 1.748 | 0.535 | 0.0180 | 2.732 | 2.914 | -0.182 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-16B | 0-3 | 1.291 | 1.288 | 0.0011 | 2.786 | 2.065 | 0.721 |
| | | 6-9 | 1.530 | 1.290 | 0.0070 | 2.751 | 4.837 | -2.086 |
| | | 12-15 | 1.569 | 1.025 | 0.0065 | 2.717 | 3.765 | -1.048 |
| EAST PAC | BS-17B | 0-3 | 1.351 | 1.521 | 0.0012 | 2.713 | 2.898 | -0.185 |
| | | 6-9 | 1.583 | 0.913 | 0.0024 | 2.704 | 3.385 | -0.681 |
| | | 12-15 | 1.475 | 1.301 | 0.0010 | 2.694 | 3.861 | -1.167 |
| | | 18-21 | 1.511 | 1.053 | 0.0016 | 2.718 | 3.271 | -0.553 |
| | | 24-27 | 1.501 | 1.246 | 0.0008 | 2.704 | 3.995 | -1.291 |
| | | 30-33 | 1.621 | 0.821 | 0.0082 | 2.691 | 3.307 | -0.616 |
| | | 36-39 | 1.481 | 1.269 | 0.0010 | 2.748 | 3.801 | -1.053 |
| | | 42-45 | 1.498 | 1.212 | 0.0008 | 2.680 | 3.779 | -1.099 |
| | | 48-51 | 1.501 | 1.165 | 0.0013 | 2.704 | 3.605 | -0.901 |
| | | 54-57 | 1.518 | 1.167 | 0.0010 | 2.689 | 3.838 | -1.149 |
| | | 60-63 | 1.563 | 0.959 | 0.0015 | 2.678 | 3.397 | -0.719 |
| EAST PAC | BS-18B | 0-3 | 1.371 | 1.152 | 0.0009 | 2.796 | 2.394 | 0.402 |
| | | 6-9 | 1.312 | 1.272 | 0.0007 | 2.795 | 2.175 | 0.620 |
| | | 12-15 | 1.434 | 1.207 | 0.0009 | 2.773 | 3.012 | -0.239 |
| | | 18-21 | 1.456 | 1.221 | 0.0009 | 2.772 | 3.285 | -0.513 |
| | | 24-27 | 1.514 | 1.144 | 0.0015 | 2.804 | 3.675 | -0.871 |
| | | 30-33 | 1.503 | 1.218 | 0.0007 | 2.797 | 3.880 | -1.083 |
| | | 36-39 | 1.510 | 1.236 | 0.0008 | 2.789 | 4.085 | -1.296 |
| | | 42-45 | 1.494 | 1.169 | 0.0009 | 2.797 | 3.536 | -0.739 |
| | | 48-51 | 1.487 | 1.230 | 0.0008 | 2.820 | 3.708 | -0.888 |
| | | 54-57 | 1.490 | 1.206 | 0.0008 | 2.825 | 3.642 | -0.817 |
| | | 60-63 | 1.493 | 1.144 | 0.0016 | 2.789 | 3.424 | -0.635 |
| | | 66-69 | 1.499 | 1.135 | 0.0012 | 2.792 | 3.457 | -0.665 |
| | | 72-75 | 1.488 | 1.106 | 0.0009 | 2.797 | 3.233 | -0.436 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-19B | 0-3 | 1.388 | 1.535 | 0.0019 | 2.740 | 3.432 | -0.692 |
| | | 6-9 | 1.319 | 1.492 | 0.0007 | 2.686 | 2.517 | 0.169 |
| | | 12-15 | 1.323 | 1.696 | 0.0008 | 2.694 | 2.926 | -0.232 |
| | | 18-21 | 1.305 | 1.789 | 0.0009 | 2.712 | 2.872 | -0.160 |
| | | 24-27 | 1.378 | 1.055 | 0.0020 | 2.672 | 2.292 | 0.380 |
| | | 30-33 | 1.386 | 1.202 | 0.0023 | 2.689 | 2.586 | 0.103 |
| | | 36-39 | 1.352 | 1.214 | 0.0017 | 2.677 | 2.361 | 0.316 |
| | | 42-45 | 1.306 | 1.716 | 0.0009 | 2.693 | 2.750 | -0.057 |
| | | 48-51 | 1.343 | 1.458 | 0.0008 | 2.749 | 2.687 | 0.062 |
| | | 54-57 | 1.335 | 1.463 | 0.0010 | 2.765 | 2.618 | 0.147 |
| | | 60-63 | 1.365 | 1.374 | 0.0010 | 2.746 | 2.738 | 0.008 |
| | | 66-69 | 1.348 | 1.378 | 0.0009 | 2.706 | 2.590 | 0.116 |
| | | 72-75 | 1.349 | 1.387 | 0.0007 | 2.722 | 2.615 | 0.107 |
| | | 78-81 | 1.343 | 1.384 | 0.0008 | 2.711 | 2.557 | 0.154 |
| EAST PAC | BS-20B | 0-3 | 1.391 | 1.437 | 0.0017 | 2.707 | 3.175 | -0.468 |
| | | 6-9 | 1.325 | 1.496 | 0.0011 | 2.651 | 2.579 | 0.072 |
| | | 12-15 | 1.368 | 1.354 | 0.0009 | 2.668 | 2.727 | -0.059 |
| | | 18-21 | 1.315 | 1.557 | 0.0014 | 2.670 | 2.581 | 0.089 |
| | | 24-27 | 1.442 | 1.032 | 0.0026 | 2.681 | 2.651 | 0.030 |
| | | 30-33 | 1.713 | 0.483 | 0.0220 | 2.666 | 2.613 | 0.053 |
| EAST PAC | BS-21B | 0-3 | 1.315 | 1.493 | 0.0009 | 2.711 | 2.483 | 0.228 |
| | | 6-9 | 1.335 | 1.592 | 0.0010 | 2.660 | 2.861 | -0.201 |
| | | 12-15 | 1.307 | 1.686 | 0.0010 | 2.651 | 2.709 | -0.058 |
| | | 18-21 | 1.328 | 1.539 | 0.0016 | 2.664 | 2.682 | -0.018 |
| | | 24-27 | 1.283 | 1.667 | 0.0009 | 2.664 | 2.429 | 0.235 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-22B | 0-3 | 1.304 | 1.628 | 0.0011 | 2.715 | 2.582 | 0.133 |
| | | 6-9 | 1.374 | 1.276 | 0.0009 | 2.722 | 2.628 | 0.094 |
| | | 12-15 | 1.355 | 1.445 | 0.0007 | 2.721 | 2.782 | -0.061 |
| | | 18-21 | 1.402 | 1.186 | 0.0018 | 2.751 | 2.680 | 0.071 |
| | | 24-27 | 1.365 | 1.371 | 0.0008 | 2.669 | 2.732 | -0.063 |
| | | 30-33 | 1.361 | 1.486 | 0.0010 | 2.705 | 2.936 | -0.231 |
| | | 36-39 | 1.337 | 1.496 | 0.0006 | 2.680 | 2.696 | -0.016 |
| | | 42-45 | 1.403 | 1.381 | 0.0016 | 2.772 | 3.164 | -0.392 |
| | | 48-51 | 1.350 | 1.513 | 0.0007 | 2.678 | 2.870 | -0.192 |
| | | 54-57 | 1.344 | 1.338 | 0.0011 | 2.753 | 2.490 | 0.263 |
| | | 60-63 | 1.339 | 1.307 | 0.0010 | 2.698 | 2.397 | 0.301 |
| | | 66-69 | 1.352 | 0.986 | 0.0017 | 2.678 | 2.071 | 0.607 |
| | | 72-75 | 1.357 | 1.396 | 0.0008 | 2.685 | 2.705 | -0.020 |
| | | 78-81 | 1.347 | 1.257 | 0.0009 | 2.697 | 2.389 | 0.308 |
| | | 84-87 | 1.374 | 1.335 | 0.0007 | 2.682 | 2.744 | -0.062 |
| EAST PAC | BS-23B | 0-3 | 1.346 | 1.369 | 0.0010 | 2.769 | 2.557 | 0.212 |
| | | 6-9 | 1.360 | 1.383 | 0.0008 | 2.715 | 2.709 | 0.006 |
| | | 12-15 | 1.373 | 1.261 | 0.0015 | 2.684 | 2.592 | 0.092 |
| | | 18-21 | 1.362 | 1.311 | 0.0011 | 2.713 | 2.592 | 0.121 |
| | | 24-27 | 1.362 | 1.441 | 0.0010 | 2.720 | 2.847 | -0.127 |
| | | 30-33 | 1.338 | 1.415 | 0.0007 | 2.725 | 2.565 | 0.160 |
| | | 36-39 | 1.388 | 1.325 | 0.0014 | 2.692 | 2.857 | -0.165 |
| | | 42-45 | 1.385 | 1.041 | 0.0033 | 2.754 | 2.311 | 0.443 |
| | | 48-51 | 1.343 | 1.311 | 0.0012 | 2.712 | 2.440 | 0.272 |
| | | 54-57 | 1.408 | 1.067 | 0.0016 | 2.690 | 2.494 | 0.196 |
| | | 60-63 | 1.377 | 1.288 | 0.0016 | 2.666 | 2.677 | -0.011 |
| | | 66-69 | 1.379 | 1.234 | 0.0008 | 2.717 | 2.591 | 0.126 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST PAC | BS-24B | 0-3 | 1.439 | 1.164 | 0.0009 | 2.821 | 2.943 | -0.122 |
| | | 6-9 | 1.385 | 1.191 | 0.0010 | 2.810 | 2.558 | 0.252 |
| | | 12-15 | 1.420 | 1.182 | 0.0009 | 2.759 | 2.820 | -0.061 |
| | | 18-21 | 1.423 | 1.170 | 0.0009 | 2.767 | 2.817 | -0.050 |
| | | 24-27 | 1.404 | 1.103 | 0.0009 | 2.761 | 2.533 | 0.228 |
| | | 30-33 | 1.392 | 1.202 | 0.0008 | 2.842 | 2.632 | 0.210 |
| | | 36-39 | 1.383 | 1.266 | 0.0013 | 2.753 | 2.685 | 0.068 |
| | | 42-45 | 1.418 | 1.163 | 0.0008 | 2.773 | 2.759 | 0.014 |
| | | 48-51 | 1.433 | 1.142 | 0.0008 | 2.814 | 2.835 | -0.021 |
| | | 54-57 | 1.393 | 1.136 | 0.0009 | 2.759 | 2.516 | 0.243 |
| | | 60-63 | 1.408 | 1.195 | 0.0009 | 2.772 | 2.748 | 0.024 |
| | | 66-69 | 1.419 | 1.147 | 0.0009 | 2.766 | 2.732 | 0.034 |
| | | 72-75 | 1.400 | 1.100 | 0.0009 | 2.821 | 2.500 | 0.321 |
| | | 78-81 | 1.403 | 1.161 | 0.0009 | 2.793 | 2.637 | 0.156 |
| EAST PAC | BS-25B | 0-3 | 1.352 | 1.191 | 0.0010 | 2.797 | 2.328 | 0.469 |
| | | 6-9 | 1.400 | 1.111 | 0.0007 | 2.805 | 2.520 | 0.285 |
| | | 12-15 | 1.383 | 1.198 | 0.0009 | 2.813 | 2.556 | 0.257 |
| | | 18-21 | 1.413 | 1.072 | 0.0009 | 2.820 | 2.536 | 0.284 |
| | | 24-27 | 1.388 | 1.212 | 0.0009 | 2.851 | 2.620 | 0.231 |
| | | 30-33 | 1.381 | 1.233 | 0.0008 | 2.868 | 2.605 | 0.263 |
| | | 36-39 | 1.399 | 1.118 | 0.0007 | 2.789 | 2.526 | 0.263 |
| | | 42-45 | 1.402 | 1.139 | 0.0015 | 2.797 | 2.586 | 0.211 |
| | | 48-51 | 1.385 | 1.171 | 0.0009 | 2.813 | 2.522 | 0.291 |
| | | 54-57 | 1.391 | 1.190 | 0.0008 | 2.863 | 2.601 | 0.262 |
| | | 60-63 | 1.417 | 1.070 | 0.0008 | 2.818 | 2.559 | 0.259 |
| | | 66-69 | 1.380 | 1.096 | 0.0009 | 2.843 | 2.365 | 0.478 |
| | | 72-75 | 1.424 | 1.040 | 0.0008 | 2.814 | 2.547 | 0.267 |
| | | 78-81 | 1.378 | 1.053 | 0.0005 | 2.846 | 2.289 | 0.557 |
| EASTNPAC | BS-01 | 0-3 | 1.379 | 1.166 | 0.0063 | 2.644 | 2.471 | 0.173 |
| | | 6-9 | 1.416 | 1.280 | 0.0000 | 2.578 | 3.029 | -0.451 |
| | | 12-15 | 1.380 | 1.255 | 0.0030 | 2.463 | 2.638 | -0.175 |
| | | 18-21 | 1.409 | 1.132 | 0.0000 | 2.604 | 2.624 | -0.020 |
| | | 24-27 | 1.408 | 1.165 | 0.0021 | 2.677 | 2.684 | -0.007 |
| | | 30-33 | 1.413 | 1.215 | 0.0000 | 2.322 | 2.836 | -0.514 |
| | | 36-39 | 1.411 | 1.066 | 0.0020 | 2.759 | 2.511 | 0.248 |
| | | 42-45 | 1.409 | 1.105 | 0.0000 | 2.681 | 2.571 | 0.110 |
| | | 48-51 | 1.417 | 1.174 | 0.0028 | 2.744 | 2.776 | -0.032 |
| | | 55-58 | 1.497 | 1.092 | 0.0000 | 2.651 | 3.274 | -0.623 |
| | | 58-62 | 1.419 | 1.155 | 0.0025 | 2.600 | 2.750 | -0.150 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EASTNPAC | BS-02 | 0-3 | 1.356 | 1.418 | 0.0014 | 2.789 | 2.738 | 0.051 |
| | | 6-9 | 1.325 | 1.517 | 0.0000 | 2.692 | 2.614 | 0.078 |
| | | 12-15 | 1.315 | 1.424 | 0.0012 | 2.835 | 2.398 | 0.437 |
| | | 18-21 | 1.374 | 1.500 | 0.0000 | 2.602 | 3.130 | -0.528 |
| | | 24-27 | 1.319 | 1.471 | 0.0018 | 2.848 | 2.476 | 0.372 |
| | | 30-33 | 1.417 | 1.153 | 0.0000 | 2.637 | 2.729 | -0.092 |
| | | 36-39 | 1.395 | 1.012 | 0.0022 | 2.795 | 2.324 | 0.471 |
| | | 42-45 | 1.451 | 1.075 | 0.0000 | 3.012 | 2.817 | 0.195 |
| | | 48-51 | 1.528 | 0.687 | 0.0140 | 3.123 | 2.398 | 0.725 |
| | | 54-57 | 1.642 | 1.630 | 0.0000 | 2.709 | -35.342 | 38.051 |
| | | 60-63 | 1.575 | 0.896 | 0.0240 | 2.663 | 3.211 | -0.548 |
| EASTNPAC | BS-03 | 0-3 | 1.315 | 1.501 | 0.0003 | 2.816 | 2.494 | 0.322 |
| | | 6-9 | 1.321 | 1.469 | 0.0000 | 2.543 | 2.500 | 0.043 |
| | | 12-15 | 1.311 | 1.672 | 0.0014 | 2.833 | 2.731 | 0.102 |
| | | 18-21 | 1.365 | 1.262 | 0.0000 | 2.642 | 2.531 | 0.111 |
| | | 24-27 | 1.341 | 1.505 | 0.0005 | 2.520 | 2.755 | -0.235 |
| | | 30-33 | 1.365 | 0.833 | 0.0000 | 2.582 | 1.961 | 0.621 |
| | | 36-39 | 1.414 | 0.922 | 0.0018 | 2.570 | 2.287 | 0.283 |
| EASTNPAC | BS-04 | 0-3 | 1.289 | 1.769 | 0.0013 | 2.690 | 2.637 | 0.053 |
| | | 6-9 | 1.308 | 1.821 | 0.0000 | 2.513 | 2.979 | -0.466 |
| | | 12-15 | 1.357 | 1.415 | 0.0019 | 2.574 | 2.742 | -0.168 |
| | | 18-21 | 1.413 | 1.165 | 0.0000 | 2.597 | 2.723 | -0.126 |
| | | 24-27 | 1.365 | 1.331 | 0.0029 | 2.756 | 2.655 | 0.101 |
| | | 30-33 | 1.365 | 1.465 | 0.0000 | 2.588 | 2.934 | -0.346 |
| | | 36-39 | 1.330 | 0.634 | 0.0005 | 2.776 | 1.682 | 1.094 |
| | | 42-45 | 1.393 | 1.225 | 0.0000 | 2.542 | 2.686 | -0.144 |
| | | 48-51 | 1.374 | 1.383 | 0.0021 | 2.718 | 2.846 | -0.128 |
| | | 54-57 | 1.403 | 1.260 | 0.0000 | 2.573 | 2.850 | -0.277 |
| | | 60-63 | 1.390 | 1.237 | 0.0018 | 2.800 | 2.686 | 0.114 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EASTNPAC | BS-05 | 2-4 | 1.281 | 1.779 | 0.0014 | 2.633 | 2.561 | 0.072 |
| | | 7-10 | 1.320 | 1.793 | 0.0000 | 2.556 | 3.097 | -0.541 |
| | | 14-16 | 1.303 | 1.487 | 0.0017 | 2.742 | 2.372 | 0.370 |
| | | 19-22 | 1.321 | 1.428 | 0.0000 | 2.526 | 2.439 | 0.087 |
| | | 26-28 | 1.359 | 1.309 | 0.0015 | 2.722 | 2.564 | 0.158 |
| | | 31-34 | 1.363 | 1.449 | 0.0000 | 2.530 | 2.875 | -0.345 |
| | | 38-40 | 1.347 | 1.308 | 0.0018 | 2.705 | 2.466 | 0.239 |
| | | 44-47 | 1.317 | 1.299 | 0.0000 | 2.570 | 2.239 | 0.331 |
| | | 50-52 | 1.446 | 1.220 | 0.0044 | 2.724 | 3.172 | -0.448 |
| | | 56-59 | 1.367 | 1.345 | 0.0000 | 2.584 | 2.700 | -0.116 |
| | | 62-64 | 1.366 | 1.366 | 0.0019 | 2.860 | 2.732 | 0.128 |
| | | 67-70 | 1.428 | 1.304 | 0.0000 | 2.597 | 3.232 | -0.635 |
| | | 74-76 | 1.359 | 1.303 | 0.0013 | 2.892 | 2.553 | 0.339 |
| EASTNPAC | BS-06 | 0-3 | 1.318 | 1.386 | 0.0110 | 2.647 | 2.357 | 0.290 |
| | | 6-9 | 1.172 | 1.423 | 0.0000 | 2.430 | 1.552 | 0.878 |
| | | 12-15 | 1.297 | 1.601 | 0.0057 | 2.588 | 2.473 | 0.115 |
| | | 18-21 | 1.266 | 1.603 | 0.0000 | 2.532 | 2.207 | 0.325 |
| | | 24-27 | 1.332 | 1.489 | 0.0043 | 2.547 | 2.634 | -0.087 |
| | | 30-33 | 1.370 | 1.387 | 0.0033 | 2.451 | 2.814 | -0.363 |
| | | 36-39 | 1.346 | 1.530 | 0.0000 | 2.713 | 2.860 | -0.147 |
| | | 42-45 | 1.380 | 1.424 | 0.0000 | 2.498 | 3.007 | -0.509 |
| | | 48-51 | 1.368 | 1.236 | 0.0021 | 2.652 | 2.509 | 0.143 |
| EASTNPAC | BS-07 | 0-3 | 1.271 | 2.020 | 0.0016 | 2.741 | 2.808 | -0.067 |
| | | 6-9 | 1.302 | 1.607 | 0.0000 | 2.538 | 2.530 | 0.008 |
| | | 12-15 | 1.297 | 1.595 | 0.0017 | 2.687 | 2.464 | 0.223 |
| | | 18-21 | 1.356 | 1.435 | 0.0000 | 2.624 | 2.772 | -0.148 |
| | | 24-27 | 1.356 | 1.430 | 0.0017 | 2.674 | 2.762 | -0.088 |
| | | 30-33 | 1.369 | 1.394 | 0.0000 | 2.571 | 2.819 | -0.248 |
| | | 36-39 | 1.367 | 1.348 | 0.0017 | 2.688 | 2.705 | -0.017 |
| | | 42-45 | 1.389 | 1.339 | 0.0000 | 2.651 | 2.899 | -0.248 |
| | | 48-51 | 1.355 | 1.400 | 0.0028 | 2.681 | 2.694 | -0.013 |
| | | 54-57 | 1.385 | 1.344 | 0.0000 | 2.595 | 2.870 | -0.275 |
| | | 60-63 | 1.359 | 1.383 | 0.0002 | 2.652 | 2.699 | -0.047 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EASTNPAC | BS-08 | 0-3 | 1.291 | 1.640 | 0.0002 | 2.624 | 2.470 | 0.154 |
| | | 6-9 | 1.326 | 1.608 | 0.0002 | 2.535 | 2.787 | -0.252 |
| | | 12-15 | 1.343 | 1.491 | 0.0000 | 2.732 | 2.749 | -0.017 |
| | | 18-21 | 1.337 | 1.520 | 0.0000 | 2.478 | 2.741 | -0.263 |
| | | 24-27 | 1.349 | 1.417 | 0.0006 | 2.623 | 2.669 | -0.046 |
| | | 30-33 | 1.372 | 1.291 | 0.0000 | 2.517 | 2.640 | -0.123 |
| | | 36-39 | 1.342 | 1.366 | 0.0003 | 2.652 | 2.519 | 0.133 |
| | | 42-45 | 1.342 | 1.385 | 0.0000 | 2.578 | 2.550 | 0.028 |
| | | 48-51 | 1.362 | 2.119 | 0.0006 | 2.680 | 5.847 | -3.167 |
| | | 54-57 | 1.310 | 1.278 | 0.0000 | 2.589 | 2.170 | 0.419 |
| | | 60-63 | 1.368 | 1.325 | 0.0003 | 2.631 | 2.670 | -0.039 |
| | | 66-69 | 1.363 | 1.295 | 0.0005 | 2.571 | 2.572 | -0.001 |
| | | 72-75 | 1.368 | 1.333 | 0.0000 | 2.722 | 2.685 | 0.037 |
| | | 78-81 | 1.368 | 1.483 | 0.0000 | 2.552 | 3.012 | -0.460 |
| | | 84-87 | 1.361 | 1.285 | 0.0004 | 2.578 | 2.539 | 0.039 |
| | | 90-93 | 1.391 | 1.414 | 0.0000 | 2.601 | 3.111 | -0.510 |
| | | 96-99 | 1.370 | 1.295 | 0.0017 | 2.656 | 2.630 | 0.026 |
| | | 102-105 | 1.421 | 1.267 | 0.0000 | 2.625 | 3.045 | -0.420 |
| EASTNPAC | BS-09 | 0-3 | 1.289 | 1.613 | 0.0013 | 2.790 | 2.415 | 0.375 |
| | | 6-9 | 1.321 | 1.697 | 0.0014 | 2.516 | 2.902 | -0.386 |
| | | 12-15 | 1.315 | 1.699 | 0.0000 | 2.768 | 2.829 | -0.061 |
| | | 18-21 | 1.347 | 1.482 | 0.0000 | 2.521 | 2.773 | -0.252 |
| | | 24-27 | 1.355 | 1.441 | 0.0014 | 2.780 | 2.774 | 0.006 |
| | | 30-33 | 1.349 | 1.517 | 0.0000 | 2.481 | 2.867 | -0.386 |
| | | 36-39 | 1.337 | 1.515 | 0.0014 | 2.742 | 2.732 | 0.010 |
| | | 42-45 | 1.291 | 1.316 | 0.0000 | 2.618 | 2.092 | 0.526 |
| | | 48-51 | 1.343 | 1.393 | 0.0007 | 2.759 | 2.572 | 0.187 |
| | | 54-57 | 1.384 | 1.421 | 0.0000 | 2.677 | 3.046 | -0.369 |
| | | 60-63 | 1.362 | 1.353 | 0.0013 | 2.758 | 2.669 | 0.089 |
| | | 66-69 | 1.349 | 1.467 | 0.0000 | 2.602 | 2.764 | -0.162 |
| | | 72-75 | 1.307 | 1.623 | 0.0014 | 2.801 | 2.605 | 0.196 |
| | | 78-81 | 1.372 | 1.869 | 0.0000 | 2.449 | 4.502 | -2.053 |
| | | 84-87 | 1.361 | 1.536 | 0.0006 | 2.872 | 3.055 | -0.183 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EASTNPAC | BS-10 | 0-3 | 1.277 | 1.555 | 0.0015 | 2.789 | 2.243 | 0.546 |
| | | 6-9 | 1.304 | 1.387 | 0.0000 | 2.592 | 2.255 | 0.337 |
| | | 12-15 | 1.361 | 1.969 | 0.0017 | 2.725 | 4.706 | -1.981 |
| | | 18-21 | 1.398 | 1.358 | 0.0000 | 2.594 | 3.042 | -0.448 |
| | | 24-27 | 1.375 | 1.382 | 0.0015 | 2.743 | 2.854 | -0.111 |
| | | 30-33 | 1.389 | 1.483 | 0.0000 | 2.594 | 3.283 | -0.689 |
| | | 36-39 | 1.356 | 1.273 | 0.0012 | 2.748 | 2.480 | 0.268 |
| | | 42-45 | 1.596 | 0.555 | 0.0000 | 2.607 | 2.385 | 0.222 |
| | | 48-51 | 1.358 | 1.439 | 0.0014 | 2.884 | 2.801 | 0.083 |
| | | 54-57 | 1.428 | 1.482 | 0.0000 | 2.635 | 3.905 | -1.270 |
| | | 60-63 | 1.382 | 1.274 | 0.0035 | 2.790 | 2.692 | 0.098 |
| | | 66-69 | 1.468 | 1.157 | 0.0000 | 2.682 | 3.202 | -0.520 |
| | | 72-75 | 1.406 | 1.229 | 0.0025 | 2.844 | 2.806 | 0.038 |
| FNP-CIS | JD-01 | 0-3 | 1.441 | 0.956 | 0.0067 | 2.505 | 2.491 | 0.014 |
| | | 6-9 | 1.529 | 0.763 | 0.0094 | 2.577 | 2.564 | 0.013 |
| | | 12-15 | 1.568 | 0.652 | 0.0097 | 2.539 | 2.490 | 0.049 |
| | | 18-21 | 1.651 | 0.573 | 0.0160 | 2.571 | 2.633 | -0.062 |
| | | 24-27 | 1.649 | 0.573 | 0.0180 | 2.548 | 2.625 | -0.077 |
| | | 30-33 | 1.679 | 0.557 | 0.0190 | 2.568 | 2.700 | -0.132 |
| | | 36-39 | 1.667 | 0.587 | 0.0250 | 2.587 | 2.740 | -0.153 |
| FNP-CIS | JD-02 | 0-3 | 1.687 | 0.600 | 0.0460 | 2.526 | 2.870 | -0.344 |
| | | 6-9 | 1.659 | 0.520 | 0.0490 | 2.571 | 2.524 | 0.047 |
| | | 12-15 | 1.669 | 0.382 | 0.0510 | 2.586 | 2.242 | 0.344 |
| | | 18-21 | 1.673 | 0.525 | 0.0480 | 2.562 | 2.587 | -0.025 |
| | | 24-27 | 1.640 | 0.562 | 0.0280 | 2.551 | 2.561 | -0.010 |
| | | 30-33 | 1.650 | 0.538 | 0.0290 | 2.569 | 2.537 | 0.032 |
| | | 36-39 | 1.622 | 0.592 | 0.0230 | 2.559 | 2.567 | -0.008 |
| FNP-CIS | JD-03 | 0-3 | 1.295 | 1.761 | 0.0076 | 2.096 | 2.695 | -0.599 |
| | | 6-9 | 1.287 | 1.307 | 0.0078 | 2.209 | 2.060 | 0.149 |
| | | 12-15 | 1.275 | 1.615 | 0.0043 | 2.155 | 2.294 | -0.139 |
| | | 18-21 | 1.274 | 1.463 | 0.0039 | 2.211 | 2.126 | 0.085 |
| | | 24-27 | 1.266 | 1.614 | 0.0038 | 2.115 | 2.218 | -0.103 |
| | | 30-33 | 1.377 | 1.519 | 0.0034 | 2.205 | 3.222 | -1.017 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| ENP-CIS | JD-04 | 0-3 | 1.638 | 0.554 | 0.0610 | 2.586 | 2.533 | 0.053 |
| | | 6-9 | 1.703 | 0.518 | 0.0420 | 2.575 | 2.678 | -0.102 |
| | | 12-15 | 1.654 | 0.637 | 0.0280 | 2.557 | 2.835 | -0.278 |
| | | 18-21 | 1.744 | 0.516 | 0.0690 | 2.585 | 2.831 | -0.246 |
| | | 24-27 | 1.754 | 0.454 | 0.0680 | 2.585 | 2.667 | -0.082 |
| | | 30-33 | 1.724 | 0.507 | 0.0550 | 2.590 | 2.724 | -0.134 |
| | | 36-39 | 1.779 | 0.339 | 0.0760 | 2.599 | 2.417 | 0.182 |
| | | 42-45 | 1.664 | 0.666 | 0.0760 | 2.619 | 2.983 | -0.364 |
| | | 48-51 | 1.746 | 0.459 | 0.0740 | 2.555 | 2.655 | -0.100 |
| | | 54-57 | 1.752 | 0.551 | 0.0560 | 2.567 | 2.992 | -0.425 |
| ENP-CIS | JD-05 | 0-3 | 1.681 | 0.461 | 0.1300 | 2.679 | 2.450 | 0.229 |
| | | 6-9 | 1.386 | 0.874 | 0.0040 | 2.366 | 2.092 | 0.274 |
| | | 12-15 | 1.464 | 0.784 | 0.0051 | 2.370 | 2.301 | 0.069 |
| | | 18-21 | 1.462 | 0.924 | 0.0049 | 2.459 | 2.551 | -0.092 |
| | | 24-27 | 1.503 | 0.929 | 0.0044 | 2.483 | 2.821 | -0.338 |
| ENP-CIS | JD-06 | 0-3 | 1.654 | 0.672 | 0.0910 | 2.642 | 2.951 | -0.309 |
| | | 6-9 | 1.664 | 0.595 | 0.1270 | 2.729 | 2.751 | -0.022 |
| | | 12-15 | 1.711 | 0.604 | 0.1000 | 2.643 | 2.999 | -0.356 |
| | | 18-21 | 1.777 | 0.481 | 0.1100 | 2.686 | 2.837 | -0.151 |
| | | 24-27 | 1.719 | 0.546 | 0.0850 | 2.614 | 2.830 | -0.216 |
| | | 30-33 | 1.845 | 0.447 | 0.1200 | 2.662 | 2.965 | -0.303 |
| ENP-CIS | JD-07 | 0-3 | 1.648 | 0.454 | 0.0650 | 2.655 | 2.335 | 0.320 |
| | | 6-9 | 1.649 | 0.599 | 0.0560 | 2.691 | 2.698 | -0.007 |
| | | 12-15 | 1.719 | 0.516 | 0.0560 | 2.621 | 2.733 | -0.112 |
| | | 18-21 | 1.709 | 0.555 | 0.0600 | 2.649 | 2.818 | -0.169 |
| | | 24-27 | 1.785 | 0.393 | 0.0830 | 2.648 | 2.581 | 0.067 |
| | | 30-33 | 1.691 | 0.461 | 0.0560 | 2.703 | 2.481 | 0.222 |
| | | 36-39 | 1.770 | 0.459 | 0.0750 | 2.613 | 2.738 | -0.125 |
| | | 42-45 | 1.783 | 0.878 | 0.0720 | 2.653 | 5.705 | -3.052 |
| | | 48-51 | 1.801 | 0.823 | 0.0610 | 2.763 | 5.285 | -2.522 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY ACP | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| ENP-CIS | JD-08 | 0-3 | 1.704 | 0.613 | 0.0960 | 2.589 | 2.998 | -0.409 |
| | | 6-9 | 1.675 | 0.588 | 0.0970 | 2.646 | 2.777 | -0.131 |
| | | 12-15 | 1.725 | 0.521 | 0.0800 | 2.638 | 2.772 | -0.134 |
| | | 18-21 | 1.715 | 0.520 | 0.0870 | 2.597 | 2.730 | -0.133 |
| | | 24-27 | 1.771 | 0.451 | 0.0950 | 2.638 | 2.715 | -0.077 |
| | | 30-33 | 1.813 | 0.443 | 0.0950 | 2.655 | 2.834 | -0.179 |
| ENP-CIS | JD-09 | 0-3 | 1.534 | 0.957 | 0.0750 | 2.254 | 3.137 | -0.883 |
| | | 6-9 | 1.367 | 1.150 | 0.0095 | 2.214 | 2.365 | -0.151 |
| | | 12-15 | 1.357 | 1.164 | 0.0110 | 2.239 | 2.322 | -0.083 |
| | | 18-21 | 1.344 | 1.216 | 0.0083 | 2.203 | 2.310 | -0.107 |
| | | 24-27 | 1.327 | 1.181 | 0.0079 | 2.278 | 2.162 | 0.116 |

# APPENDIX F

## COMPUTER OUTPUT FOR HYDROGRAPHIC OFFICE DATA

The computer output for the U. S. Hydrographic Office data is contained in this appendix. Specific gravity values were determined by the computer program in Appendix D and the bottle pycnometer method. Median diameters are in microns. A zero reading in the median diameter column indicates that no grain size analysis data was available for that interval.

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST ATL | A-23 | 2-4 | 1.440 | 1.093 | 0.0000 | 2.791 | 2.774 | 0.017 |
| | | 8-10 | 1.480 | 0.936 | 0.0000 | 2.764 | 2.687 | 0.077 |
| | | 14-16 | 1.510 | 0.874 | 0.0000 | 2.788 | 2.724 | 0.064 |
| | | 20-22 | 1.530 | 0.823 | 0.0000 | 2.795 | 2.714 | 0.081 |
| | | 26-28 | 1.550 | 0.773 | 0.0000 | 2.796 | 2.696 | 0.100 |
| EAST ATL | A-31 | 0-2 | 1.390 | 1.161 | 0.0000 | 2.796 | 2.540 | 0.256 |
| | | 2-4 | 1.450 | 0.987 | 3.2000 | 2.776 | 2.674 | 0.102 |
| | | 6-8 | 1.470 | 0.856 | 0.0000 | 2.806 | 2.460 | 0.346 |
| | | 8-10 | 1.510 | 0.840 | 2.8000 | 2.776 | 2.642 | 0.134 |
| | | 12-14 | 1.550 | 0.778 | 0.0000 | 2.771 | 2.709 | 0.062 |
| | | 14-16 | 1.540 | 0.777 | 3.0000 | 2.783 | 2.653 | 0.130 |
| | | 18-20 | 1.580 | 0.716 | 0.0000 | 2.807 | 2.702 | 0.105 |
| | | 20-22 | 1.610 | 0.647 | 7.7000 | 2.753 | 2.660 | 0.093 |
| | | 24-26 | 1.630 | 0.624 | 0.0000 | 2.774 | 2.686 | 0.088 |
| | | 26-28 | 1.630 | 0.631 | 11.0000 | 2.773 | 2.706 | 0.067 |
| | | 30-32 | 1.660 | 0.578 | 0.0000 | 2.770 | 2.684 | 0.086 |
| | | 32-34 | 1.660 | 0.610 | 5.2000 | 2.789 | 2.779 | 0.010 |
| | | 36-38 | 1.660 | 0.624 | 0.0000 | 2.765 | 2.822 | -0.057 |
| | | 38-40 | 1.640 | 0.609 | 2.6000 | 2.769 | 2.687 | 0.082 |
| WEST MED | B-93 | 0-2 | 1.500 | 0.841 | 0.0000 | 2.798 | 2.588 | 0.210 |
| | | 2-4 | 1.540 | 0.800 | 2.3000 | 2.807 | 2.711 | 0.096 |
| | | 6-8 | 1.590 | 0.699 | 0.0000 | 2.815 | 2.706 | 0.109 |
| | | 8-10 | 1.610 | 0.661 | 2.5000 | 2.800 | 2.698 | 0.102 |
| | | 10-12 | 1.630 | 0.596 | 0.0000 | 2.806 | 2.610 | 0.196 |
| | | 12-14 | 1.640 | 0.605 | 0.0000 | 2.792 | 2.676 | 0.116 |
| | | 14-16 | 1.640 | 0.623 | 3.2000 | 2.822 | 2.728 | 0.094 |
| | | 18-20 | 1.660 | 0.577 | 0.0000 | 2.807 | 2.681 | 0.126 |
| | | 20-22 | 1.670 | 0.557 | 2.5000 | 2.805 | 2.664 | 0.141 |
| | | 24-26 | 1.690 | 0.539 | 0.0000 | 2.800 | 2.691 | 0.109 |
| | | 26-28 | 1.680 | 0.545 | 2.3000 | 2.804 | 2.669 | 0.135 |
| | | 30-32 | 1.690 | 0.529 | 0.0000 | 2.784 | 2.661 | 0.123 |
| | | 34-36 | 1.720 | 0.524 | 0.0000 | 2.794 | 2.762 | 0.032 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| WEST MED | P-8F | 0-2 | 1.450 | 0.950 | 0.0000 | 2.796 | 2.533 | 0.263 |
| | | 2-4 | 1.490 | 0.844 | 2.0000 | 2.791 | 2.541 | 0.250 |
| | | 6-8 | 1.510 | 0.826 | 0.0000 | 2.785 | 2.609 | 0.176 |
| | | 8-10 | 1.520 | 0.821 | 2.4000 | 2.773 | 2.677 | 0.096 |
| | | 12-14 | 1.560 | 0.735 | 0.0000 | 2.794 | 2.651 | 0.143 |
| | | 14-16 | 1.610 | 0.636 | 2.9000 | 2.757 | 2.631 | 0.126 |
| | | 18-20 | 1.650 | 0.585 | 0.0000 | 2.774 | 2.662 | 0.112 |
| | | 20-22 | 1.650 | 0.572 | 3.5000 | 2.771 | 2.627 | 0.144 |
| | | 24-26 | 1.700 | 0.523 | 0.0000 | 2.772 | 2.673 | 0.099 |
| | | 26-28 | 1.680 | 0.513 | 3.8000 | 2.781 | 2.580 | 0.201 |
| NE N ATL | C-15 | 0-2 | 1.720 | 0.416 | 0.0000 | 2.770 | 2.455 | 0.315 |
| | | 2-4 | 1.680 | 0.557 | 9.0000 | 2.818 | 2.704 | 0.114 |
| | | 6-8 | 1.630 | 0.614 | 0.0000 | 2.819 | 2.658 | 0.161 |
| | | 8-10 | 1.660 | 0.570 | 8.6000 | 2.811 | 2.661 | 0.150 |
| | | 12-14 | 1.690 | 0.540 | 0.0000 | 2.847 | 2.694 | 0.153 |
| | | 14-16 | 1.710 | 0.514 | 12.9000 | 2.856 | 2.693 | 0.163 |
| | | 18-20 | 1.720 | 0.507 | 0.0000 | 2.828 | 2.709 | 0.119 |
| | | 20-22 | 1.740 | 0.466 | 15.6000 | 2.802 | 2.656 | 0.146 |
| | | 24-26 | 1.710 | 0.520 | 0.0000 | 2.822 | 2.711 | 0.111 |
| | | 26-28 | 1.690 | 0.542 | 14.8000 | 2.831 | 2.700 | 0.131 |
| NE N ATL | C-19 | 0-2 | 1.300 | 1.617 | 0.0000 | 2.776 | 2.525 | 0.251 |
| | | 2-4 | 1.280 | 1.774 | 5.8000 | 2.805 | 2.543 | 0.262 |
| | | 6-8 | 1.360 | 1.374 | 0.0000 | 2.802 | 2.691 | 0.111 |
| | | 8-10 | 1.400 | 1.205 | 7.4000 | 2.839 | 2.703 | 0.136 |
| | | 12-14 | 1.350 | 1.402 | 0.0000 | 2.814 | 2.651 | 0.163 |
| | | 14-16 | 1.380 | 1.238 | 17.5000 | 2.842 | 2.606 | 0.236 |
| | | 18-20 | 1.700 | 0.531 | 0.0000 | 2.800 | 2.706 | 0.094 |
| | | 20-22 | 1.620 | 0.622 | 14.3000 | 2.810 | 2.637 | 0.173 |
| | | 24-26 | 1.680 | 0.532 | 0.0000 | 2.810 | 2.632 | 0.178 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| WEST ATL | D-1G | 0-2 | 1.450 | 1.078 | 0.0000 | 2.854 | 2.816 | 0.038 |
| | | 2-4 | 1.490 | 0.930 | 23.4000 | 2.841 | 2.737 | 0.104 |
| | | 4-6 | 1.510 | 0.895 | 0.0000 | 2.842 | 2.778 | 0.064 |
| | | 6-8 | 1.510 | 0.886 | 22.1000 | 2.835 | 2.755 | 0.080 |
| | | 8-10 | 1.540 | 0.814 | 0.0000 | 2.845 | 2.748 | 0.097 |
| | | 10-12 | 1.530 | 0.835 | 22.1000 | 2.818 | 2.745 | 0.073 |
| | | 12-14 | 1.540 | 0.829 | 0.0000 | 2.825 | 2.788 | 0.037 |
| WEST ATL | D-1P | 4-9 | 1.510 | 0.870 | 0.0000 | 2.756 | 2.714 | 0.042 |
| | | 9-13 | 1.510 | 0.887 | 0.0000 | 2.766 | 2.757 | 0.009 |
| | | 15-20 | 1.520 | 0.879 | 0.0000 | 2.779 | 2.800 | -0.021 |
| | | 20-24 | 1.510 | 0.899 | 0.0000 | 2.759 | 2.789 | -0.030 |
| | | 24-29 | 1.510 | 0.898 | 0.0000 | 2.769 | 2.786 | -0.017 |
| | | 31-35 | 1.510 | 0.909 | 0.0000 | 2.758 | 2.815 | -0.057 |
| | | 35-40 | 1.510 | 0.892 | 0.0000 | 2.770 | 2.770 | -0.000 |
| | | 40-44 | 1.510 | 0.910 | 0.0000 | 2.758 | 2.818 | -0.060 |
| | | 46-51 | 1.510 | 0.897 | 0.0000 | 2.758 | 2.783 | -0.025 |
| | | 51-55 | 1.510 | 0.897 | 0.0000 | 2.766 | 2.783 | -0.017 |
| | | 55-60 | 1.510 | 0.897 | 4.0000 | 2.768 | 2.783 | -0.015 |
| | | 62-66 | 1.510 | 0.882 | 0.0000 | 2.757 | 2.745 | 0.012 |
| | | 66-71 | 1.510 | 0.884 | 0.0000 | 2.757 | 2.750 | 0.007 |
| | | 75-77 | 1.510 | 0.897 | 0.0000 | 2.747 | 2.783 | -0.036 |
| EAST ATL | E-46 | 0-2 | 1.410 | 1.199 | 0.0000 | 2.736 | 2.773 | -0.037 |
| | | 4-6 | 1.720 | 0.529 | 4.5000 | 2.755 | 2.778 | -0.023 |
| | | 8-10 | 1.780 | 0.450 | 0.0000 | 2.761 | 2.743 | 0.018 |
| | | 12-14 | 1.720 | 0.504 | 0.0000 | 2.761 | 2.700 | 0.061 |
| | | 16-18 | 1.720 | 0.545 | 4.8000 | 2.762 | 2.831 | -0.069 |
| | | 20-22 | 1.690 | 0.562 | 0.0000 | 2.739 | 2.760 | -0.021 |
| | | 24-26 | 1.700 | 0.582 | 0.0000 | 2.760 | 2.869 | -0.109 |
| | | 28-30 | 1.710 | 0.549 | 4.8000 | 2.753 | 2.802 | -0.049 |
| | | 32-34 | 1.720 | 0.513 | 0.0000 | 2.765 | 2.727 | 0.038 |
| | | 36-38 | 1.750 | 0.502 | 0.0000 | 2.763 | 2.807 | -0.044 |
| | | 40-42 | 1.740 | 0.534 | 5.0000 | 2.759 | 2.877 | -0.118 |
| | | 44-46 | 1.740 | 0.511 | 0.0000 | 2.754 | 2.798 | -0.044 |
| | | 48-50 | 1.750 | 0.507 | 0.0000 | 2.762 | 2.824 | -0.062 |
| | | 52-54 | 1.720 | 0.520 | 0.0000 | 2.766 | 2.749 | 0.017 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| EAST ATL | F-48 | 0-2 | 1.380 | 1.288 | 0.0000 | 2.727 | 2.703 | 0.024 |
| | | 2-4 | 1.440 | 1.090 | 0.0000 | 2.728 | 2.767 | -0.039 |
| | | 4-6 | 1.480 | 0.957 | 2.7000 | 2.737 | 2.737 | -0.000 |
| | | 6-8 | 1.530 | 0.810 | 0.0000 | 2.727 | 2.681 | 0.046 |
| | | 8-10 | 1.540 | 0.767 | 0.0000 | 2.739 | 2.629 | 0.110 |
| | | 14-16 | 1.710 | 0.499 | 0.0000 | 2.746 | 2.648 | 0.098 |
| | | 16-18 | 1.660 | 0.595 | 0.0000 | 2.748 | 2.733 | 0.015 |
| | | 18-20 | 1.680 | 0.562 | 0.0000 | 2.754 | 2.719 | 0.035 |
| | | 20-22 | 1.610 | 0.666 | 2.5000 | 2.767 | 2.712 | 0.055 |
| | | 22-24 | 1.620 | 0.663 | 0.0000 | 2.767 | 2.751 | 0.016 |
| | | 24-26 | 1.610 | 0.668 | 0.0000 | 2.758 | 2.717 | 0.041 |
| | | 26-28 | 1.600 | 0.685 | 0.0000 | 2.744 | 2.716 | 0.028 |
| | | 28-30 | 1.640 | 0.619 | 0.0000 | 2.754 | 2.716 | 0.038 |
| | | 30-32 | 1.610 | 0.691 | 0.0000 | 2.746 | 2.783 | -0.037 |
| | | 32-34 | 1.620 | 0.660 | 2.2000 | 2.754 | 2.742 | 0.012 |
| | | 34-36 | 1.630 | 0.658 | 0.0000 | 2.763 | 2.784 | -0.021 |
| | | 36-38 | 1.600 | 0.703 | 0.0000 | 2.764 | 2.767 | -0.003 |
| | | 38-40 | 1.610 | 0.677 | 0.0000 | 2.758 | 2.743 | 0.015 |
| WEST ATL | F-6 | 0-4 | 1.740 | 0.487 | 14.2000 | 2.741 | 2.720 | 0.021 |
| | | 9-13 | 1.840 | 0.414 | 7.1000 | 2.743 | 2.821 | -0.078 |
| | | 15-19 | 1.860 | 0.367 | 9.8000 | 2.768 | 2.718 | 0.050 |
| | | 24-28 | 1.710 | 0.525 | 7.8000 | 2.755 | 2.726 | 0.029 |
| | | 30-34 | 1.660 | 0.573 | 6.0000 | 2.764 | 2.670 | 0.094 |
| | | 39-43 | 1.620 | 0.672 | 3.2000 | 2.770 | 2.777 | -0.007 |
| | | 45-49 | 1.600 | 0.695 | 3.6000 | 2.764 | 2.744 | 0.020 |
| | | 54-59 | 1.650 | 0.615 | 4.0000 | 2.756 | 2.749 | 0.007 |
| | | 62-66 | 1.630 | 0.649 | 6.1000 | 2.763 | 2.757 | 0.006 |
| | | 71-75 | 1.670 | 0.591 | 6.6000 | 2.763 | 2.765 | -0.002 |
| | | 77-81 | 1.710 | 0.536 | 6.7000 | 2.762 | 2.761 | 0.001 |
| | | 86-90 | 1.810 | 0.402 | 28.8000 | 2.733 | 2.684 | 0.049 |
| | | 92-96 | 1.690 | 0.556 | 7.0000 | 2.762 | 2.742 | 0.020 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| WEST ATL | F-15 | 0-2 | 1.380 | 1.219 | 0.0000 | 2.733 | 2.571 | 0.167 |
| | | 4-6 | 1.410 | 1.192 | 0.0000 | 2.730 | 2.758 | -0.028 |
| | | 9-11 | 1.430 | 1.054 | 0.0000 | 2.732 | 2.615 | 0.117 |
| | | 14-16 | 1.490 | 0.862 | 0.0000 | 2.727 | 2.580 | 0.147 |
| | | 18-20 | 1.520 | 0.849 | 0.0000 | 2.737 | 2.721 | 0.016 |
| | | 22-24 | 1.530 | 0.825 | 0.0000 | 2.749 | 2.719 | 0.030 |
| | | 27-29 | 1.530 | 0.844 | 0.0000 | 2.750 | 2.768 | -0.018 |
| | | 31-33 | 1.510 | 0.883 | 0.0000 | 2.763 | 2.747 | 0.016 |
| | | 35-37 | 1.490 | 0.957 | 0.0000 | 2.776 | 2.806 | -0.030 |
| | | 39-42 | 1.500 | 0.915 | 0.0000 | 2.770 | 2.765 | 0.005 |
| | | 44-46 | 1.450 | 1.040 | 0.0000 | 2.757 | 2.726 | 0.031 |
| | | 48-51 | 1.470 | 0.999 | 0.0000 | 2.769 | 2.771 | -0.002 |
| | | 53-55 | 1.470 | 0.992 | 1.5000 | 2.772 | 2.754 | 0.018 |
| WEST ATL | G-2 | 8-12 | 1.260 | 2.108 | 1.4000 | 2.730 | 2.788 | -0.058 |
| | | 12-16 | 1.300 | 1.759 | 1.4000 | 2.734 | 2.752 | -0.018 |
| | | 16-20 | 1.320 | 1.594 | 1.6000 | 2.751 | 2.694 | 0.057 |
| | | 35-39 | 1.370 | 1.229 | 1.6000 | 2.768 | 2.513 | 0.255 |
| | | 62-66 | 1.390 | 1.232 | 1.0000 | 2.769 | 2.676 | 0.093 |
| WEST ATL | G-8 | 8-12 | 1.290 | 1.755 | 2.0000 | 2.684 | 2.627 | 0.057 |
| | | 12-16 | 1.300 | 1.710 | 1.8000 | 2.698 | 2.669 | 0.029 |
| | | 16-20 | 1.300 | 1.669 | 2.0000 | 2.700 | 2.604 | 0.096 |
| | | 36-40 | 1.330 | 1.553 | 2.0000 | 2.710 | 2.728 | -0.018 |
| | | 64-68 | 1.360 | 1.441 | 1.8000 | 2.739 | 2.826 | -0.087 |

| CORE AREA | CORE NO | CORE INTERVAL | BULK WT DENSITY | WATER CONTENT | MEDIAN DIAMETER | SP GR BY B P | SP GR BY CAL | DIFF |
|---|---|---|---|---|---|---|---|---|
| MID PAC | H-12 | 12-14 | 1.420 | 1.168 | 0.0000 | 2.830 | 2.787 | 0.043 |
| | | 16-18 | 1.410 | 1.199 | 0.0000 | 2.713 | 2.773 | -0.060 |
| | | 20-22 | 1.420 | 1.179 | 0.0000 | 2.724 | 2.813 | -0.089 |
| | | 24-25 | 1.420 | 1.215 | 0.0000 | 2.887 | 2.900 | -0.013 |
| | | 26-27 | 1.420 | 1.224 | 0.0000 | 2.887 | 2.922 | -0.035 |
| | | 30-31 | 1.420 | 1.190 | 0.0000 | 2.887 | 2.839 | 0.048 |
| | | 34-35 | 1.450 | 1.101 | 0.0000 | 2.887 | 2.874 | 0.013 |
| | | 37-39 | 1.420 | 1.210 | 0.0000 | 2.821 | 2.887 | -0.066 |
| | | 41-43 | 1.420 | 1.223 | 0.0000 | 2.828 | 2.920 | -0.092 |
| | | 45-47 | 1.410 | 1.190 | 0.0000 | 2.782 | 2.753 | 0.029 |
| | | 49-51 | 1.420 | 1.209 | 0.0000 | 2.840 | 2.885 | -0.045 |
| | | 53-55 | 1.420 | 1.197 | 0.0000 | 2.799 | 2.856 | -0.057 |
| | | 56-58 | 1.430 | 1.202 | 0.0000 | 2.829 | 2.960 | -0.131 |
| | | 60-62 | 1.420 | 1.190 | 0.0000 | 2.809 | 2.839 | -0.030 |
| | | 65-68 | 1.420 | 1.199 | 0.0000 | 2.858 | 2.860 | -0.002 |
| MID PAC | H-13 | 6-8 | 1.400 | 1.271 | 0.0000 | 2.777 | 2.848 | -0.071 |
| | | 8-10 | 1.400 | 1.270 | 0.0000 | 2.770 | 2.846 | -0.076 |
| | | 12-14 | 1.420 | 1.175 | 0.0000 | 2.800 | 2.804 | -0.004 |
| | | 14-16 | 1.430 | 1.127 | 0.0000 | 2.783 | 2.775 | 0.008 |
| | | 18-20 | 1.430 | 1.152 | 0.0000 | 2.774 | 2.834 | -0.060 |
| | | 20-22 | 1.420 | 1.164 | 0.0000 | 2.801 | 2.778 | 0.023 |
| | | 22-24 | 1.420 | 1.168 | 0.0000 | 2.868 | 2.787 | 0.081 |
| | | 26-28 | 1.420 | 1.192 | 0.0000 | 2.830 | 2.844 | -0.014 |
| | | 30-32 | 1.410 | 1.212 | 0.0000 | 2.760 | 2.803 | -0.043 |
| | | 34-36 | 1.380 | 1.280 | 0.0000 | 2.757 | 2.687 | 0.070 |
| | | 38-41 | 1.400 | 1.242 | 0.0000 | 2.754 | 2.782 | -0.028 |
| | | 42-44 | 1.420 | 1.155 | 0.0000 | 2.783 | 2.758 | 0.025 |
| | | 46-48 | 1.420 | 1.171 | 0.0000 | 2.747 | 2.794 | -0.047 |
| | | 50-52 | 1.420 | 1.186 | 0.0000 | 2.780 | 2.829 | -0.049 |
| | | 54-56 | 1.430 | 1.109 | 0.0000 | 2.848 | 2.734 | 0.114 |

# APPENDIX G

## BIMED ANALYSIS RESULTS

This appendix contains the BIMED program results for the analysis of variance tests made on the kaolinite, montmorillonite, and quartz samples.

```
PROBLEM CODE  SGKAUL
NUMBER OF TREATMENT GROUPS      4
NUMBER OF VARIABLE FORMAT CARDS   1
DATA INPUT TAPE    5

THE VARIABLE FORMAT
(10F8.[illegible])
```

| TREATMENT GROUP | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| SAMPLE SIZE | 10 | 10 | 10 | 10 |
| MEAN | 2.7930 | 2.7480 | 2.7170 | 2.5870 |
| STANDARD DEVIATION | 0.0359 | 0.0175 | 0.0142 | 0.0082 |

ANALYSIS OF VARIANCE

| | SUM OF SQUARES | DF | MEAN SQUARE | F RATIO |
|---|---|---|---|---|
| BETWEEN GROUPS | 0.2350 | 3 | 0.0783 | 167.9882 |
| WITHIN GROUPS | 0.0168 | 36 | 0.0005 | |
| TOTAL | 0.2518 | 39 | | |

PROBLEM CODE SGKACP
NUMBER OF TREATMENT GROUPS 3
NUMBER OF VARIABLE FORMAT CARDS 1
DATA INPUT TAPE 5

THE VARIABLE FORMAT
(10F8.3)

| TREATMENT GROUP | 1 | 2 | 3 |
|---|---|---|---|
| SAMPLE SIZE | 10 | 10 | 10 |
| MEAN | 2.7927 | 2.7484 | 2.7169 |
| STANDARD DEVIATION | 0.0362 | 0.0162 | 0.0142 |

ANALYSIS OF VARIANCE

| | SUM OF SQUARES | DF | MEAN SQUARE | F RATIO |
|---|---|---|---|---|
| BETWEEN GROUPS | 0.0290 | 2 | 0.0145 | 24.5199 |
| WITHIN GROUPS | 0.0160 | 27 | 0.0006 | |
| TOTAL | 0.0450 | 29 | | |

```
PROBLEM CODE  SGMONT
NUMBER OF TREATMENT GROUPS     4
NUMBER OF VARIABLE FORMAT CARDS    1
DATA INPUT TAPE    5

THE VARIABLE FORMAT
(10F8.2)
```

| TREATMENT GROUP | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| SAMPLE SIZE | 10 | 10 | 10 | 10 |
| MEAN | 2.9150 | 2.8250 | 2.8500 | 2.7710 |
| STANDARD DEVIATION | 0.0178 | 0.0172 | 0.0211 | 0.0461 |

ANALYSIS OF VARIANCE

| | SUM OF SQUARES | DF | MEAN SQUARE | F RATIO |
|---|---|---|---|---|
| BETWEEN GROUPS | 0.1071 | 3 | 0.0357 | 44 9552 |
| WITHIN GROUPS | 0.0286 | 36 | 0.0008 | |
| TOTAL | 0.1357 | 39 | | |

```
PROBLEM CODE  SGMACP
NUMBER OF TREATMENT GROUPS      3
NUMBER OF VARIABLE FORMAT CARDS   1
DATA INPUT TAPE    5

THE VARIABLE FORMAT
(10F8.3)
```

| | | | |
|---|---|---|---|
| TREATMENT GROUP | 1 | 2 | 3 |
| SAMPLE SIZE | 10 | 10 | 10 |
| MEAN | 2,9143 | 2,8240 | 2,8499 |
| STANDARD DEVIATION | 0,0167 | 0,0179 | 0,0207 |

ANALYSIS OF VARIANCE

| | SUM OF SQUARES | DF | MEAN SQUARE | F RATIO |
|---|---|---|---|---|
| BETWEEN GROUPS | 0.0432 | 2 | 0.0216 | 63.2382 |
| WITHIN GROUPS | 0.0092 | 27 | 0.0003 | |
| TOTAL | 0.0525 | 29 | | |

```
PROBLEM CODE  SGOUTZ
NUMBER OF TREATMENT GROUPS      4
NUMBER OF VARIABLE FORMAT CARDS    1
DATA INPUT TAPE    5

THE VARIABLE FORMAT
(12F6.2)
```

| TREATMENT GROUP | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| SAMPLE SIZE | 12 | 12 | 12 | 12 |
| MEAN | 2.6508 | 2.6542 | 2.6725 | 2.6617 |
| STANDARD DEVIATION | 0.0067 | 0.0079 | 0.0075 | 0.0589 |

ANALYSIS OF VARIANCE

| | SUM OF SQUARES | DF | MEAN SQUARE | F RATIO |
|---|---|---|---|---|
| BETWEEN GROUPS | 0.0033 | 3 | 0.0011 | 1.2193 |
| WITHIN GROUPS | 0.0400 | 44 | 0.0009 | |
| TOTAL | 0.0433 | 47 | | |

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13. ABSTRACT

Accurate specific gravity measurements are required for the analysis of physical properties of marine sediments. Application of the bottle pycnometer technique, the standard determination method, is time-consuming, tedious, and perhaps subject to inaccuracies in the case of fine particulate matter. A review of methods currently in use was conducted to ascertain the present state of the art and reveal any new developments in this field. Specific gravity values for three operating modes of the air comparison pycnometer, two of which use helium, were compared with bottle pycnometer values for four test materials. The air comparison pycnometer determinations, regardless of operating mode, resulted in higher specific gravities than their counterpart bottle pycnometer values for kaolinite, montmorillonite, and marine sediment samples. The use of helium as the comparison medium in the air comparison pycnometer appears to reduce the surface active characteristics of the colloidal material. Specific gravity determinations by all four test methods agreed very well for powdered quartz samples with a known specific gravity.

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| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Specific gravity determination | | | | | | |
| Marine sediments | | | | | | |
| Air comparison pycnometer | | | | | | |
| Bottle pycnometer technique | | | | | | |

DD FORM 1 NOV 65 1473 (BACK)





A-31404

Thesis
H4393 Henderson 117849
c.1 Specific gravity determination of marine sediments.